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## USE OF BIOMIMICRY DESIGN APPROACH IN CONSTRUCTING SUSTAINABLE RESILIENT STRUCTURES (CASE STUDY: PORT OF BEIRUT)

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## USE OF BIOMIMICRY DESIGN APPROACH IN CONSTRUCTING SUSTAINABLE RESILIENT STRUCTURES (CASE STUDY: PORT OF BEIRUT)

### Abstract

Resiliency is not the same as sustainability, nor its substitute, but definitely the two concepts complement each other's. Sustainability is the avoidance of depletion of natural resources to maintain ecological balance whereas resiliency is to recover, adapt and keep going in the face of setbacks. While designing with green approach is important but what will happen to leed points if the building becomes uninhabitable due to disasters, that's where resiliency comes into play. The 2019 statistics showed that natural disasters accounted for 133 billion dollars losses and manmade ones accounted for other 7 billion in addition to 11,755 people worldwide were passed way or disappeared, all as results of failures experienced in cities structures and infrastructures when facing such contingencies, these numbers draw a concern on the current buildings industry resiliency on the global level. Currently there are two theories of resiliency; engineering which is based on technology and ecological which is based on biology. While technology exploits energy to solve problems, biology focuses on information and structure which is usually ignored by technology, therefore this research aims to propose a new approach for designing resilient structures through the use of biomimicry in order for cities to be capable of withstanding disasters. To achieve this aim, the research used a scientific approach based on tracing literature review about building's structures, in addition to disasters and how they shaped the architecture of our cities, and investigating ideas about resiliency achievement, then analyzing the "Port Of Beirut" as a case study to identify a new design approach through the use of biomimicry to improve the quality of life and strengthen the feeling of safety in the city. As a conclusion, after 3.8 billion years of nature's research and development, failures are fossils, and what surrounds us is the secret to our survival, hence biomimicry approach to be applied in order to learn from nature as a model to create sustainable designs for achieving more resilient cities.

### Keywords

Architecture, Disaster, Biomimicry, Sustainable, Resilient Structures.

## 1. INTRODUCTION

A soul to a body is what a structure to a building, as long as it is viable the building could stand still and stay alive metamorphically and not been lost, the whole building life starts and ends here. Building's Structure is the main element where all other elements are incorporated within it to produce certain required functions, it is irreplaceable, once the structure fails and cannot be repaired the functions also do and the building can no longer be used, while if any other element fails it can be simply fixed or replaced.

Building's structure mainly consists of foundations, columns, slabs, and beams, in addition to stairs and external walls, all have a certain lifetime and are designed based on equations and calculations in order to be able to face several types of external factors and forces. But when a disaster, natural or manmade arrives everything changes including those calculations and equations as they sometimes stand helpless. A disaster is defined by United Nations as *"a serious disruption of the functioning of a community or society, which involve widespread human, material, economic or environmental impacts that exceed the ability of the affected community or society to cope using its own resources"*(UNISDR,2015). On the 4<sup>th</sup> of August 2020, a devastating explosion occurred at the port of Beirut, the capital of Lebanon, due to a fire reached a warehouse storing huge amount of ammonium nitrate, in which caused about 204 deaths, more than 6000 injuries, more than US\$ 10 billion damages and left more than 300,000 citizens displaced, more over it caused the city to lose one of its major economic functions (NG, 2020). And since our modern cities are child of catastrophes, such one should be definitely a lurching point for reconsidering the way we build.

It has been said that the 20<sup>th</sup> century was the century of physics and the 21<sup>st</sup> will be the century of biology (Venter, 2004). Biomimicry is a design approach based on biology influencing design through looking to nature as a model by mimicking morphologies, functions, and ecosystems to achieve more sustainable designs and finding solutions found in nature for our problems. Nature involves many characteristics such as sustainability, high performance, economic in cutting costs, leveraging collaboration and adaptation (Philips, 2015). furthermore, and when it comes to resiliency, nature is the champion of all, where it has 3.8 billion years' experience in solving problems, moreover, as wrote by the biologist D'Arcy W. Thompson, *"every form found in nature is essentially the product of the diagram of forces acting on it or which have acted on it"* (Thompson, 1942), then why don't we create structures in the way nature does?

### 1.1 Problem Definition

The 2019 statistics showed that the total economic losses fell to around 140 \$ billion, where natural disasters accounted for 133 \$ billion and manmade ones accounted for another 7 \$ billion, more than 11,000 victims and huge number of others displaced and suffering from food insecurity, as shown in table 1. In view of these numbers, this research discusses the current built structures failure in facing such big events as they showed how non resilient, they are to the earth dynamics and not even resilient to manmade disasters, as shown in Fig. 1&2.

Table 1: 2019 Disasters Statistics  
Source: [www.preventionweb.net](http://www.preventionweb.net)

2019 Disasters Losses Statistics	Disasters		
	Man Made	Natural	Source Reference
Economic Losses	7 \$ Billion	133 \$ Billion	Swiss Re
People Affected	94.9 Million		CRED
People Displaced	24.9 Million		IDMC
People suffering from food insecurity	34 Million		WFP
Deaths	11,755		CRED



Fig.1: A 6.4 magnitude earthquake struck Albania the morning of 26 November 2019, killing 51 people

Source: [www.indepthnews.net](http://www.indepthnews.net)



Fig.2: Buildings in the Gemmayze district of Beirut after the previous day's explosion, August 4 2020

Source: [www.france24.com](http://www.france24.com)

## 1.2 Research Aim

This research aims to “propose a new design approach through the use of biomimicry on the level of mimicking nature’s resiliency to create sustainable structures capable of withstanding disasters”. The proposed hypothesis suggests that by mimicking the mechanisms and forms of some living and non-living components found in nature that were capable of surviving from the beginning of earth’s history and up till today in spite of all occurred contingencies and forces, will result in new design for resilient structures capable of handling worst natural and man-made disasters.

In order to achieve the mentioned aim, this research follows a scientific approach by introducing a literature review about building’s structures, in addition to the history of disasters, types and how they shaped our modern cities. The research will also investigate in resiliency ideas focusing on disasters resiliency and how to achieve it , then it will highlight on nature as a resiliency champion , analyzing biomimicry as an approach for mimicking some of its properties and understanding how it’s able to withstand contingencies and strong forces, then the research will conclude certain parameters to be applied on “Port of Beirut” as a case and then analyzing the effectiveness of these parameters and the new proposed design approach in supporting building’s resiliency towards disasters. To support these analyses, the author used a field method by visiting the site of the case study, captured photos, and held interviews with the users and neighbors of the project.

## 2. LITERATURE REVIEW

The literature review introduces firstly how disasters shaped modern cities, after that it will give short definitions of buildings structures , resiliency, and biomimicry, then presents a historical background on previous architectural attempts using biomimicry approach highlighting some examples of buildings designed using biomimicry to enhance structural resiliency.

### 2.1 Disasters and How They Shaped Cities

A disaster is an unforeseen event resulting in great damage or loss of life, it might be caused by a natural phenomenon occurring or by a man-made event taking place near human settlement. Throughout history disasters have been influencing architecture ,many of our present comforts, structures and infrastructure we assume it’s by default were originally born of age old distresses , for example the birth of earthquake engineering was after Lisbon catastrophic earthquake in 1755, the great Chicago fire in 1871 lead to the invention of steel skeleton system as fire proof structure which resulted in the nourishment of sky scrapers building industry, and many other inventions such as subways , aqueducts , public health regulations were established by architects ,engineers and planners in the aftermath of disasters. Therefore, natural, and man-made disasters have shaped our cities and human progress. (Thompson, 2020).

## 2.2 Definitions

### Building Structure Definition

Since prehistory, people have been constructing structures including buildings, roads, bridges, and canals. The main aim for constructing a building was to provide shelter then other services were built to serve the main aim. Within the context of the built environment, the term 'structure' refers to "anything that is constructed or built from different interrelated parts with a fixed location on the ground" (Designing Buildings Wiki, 2020). Although technological development for structures been witnessing a rise in resiliency aspects, however failures of structures still happen from time to time as a result of disasters.

### Resilience Definition

Resilience has several meanings and readings, each might differ as per the context of the field it's been used at, it is the ability to respond, absorb, and adapt to, as well as recover in a disruptive event within a certain time limit, resembled in resiliency triangle in Fig.3. The Term and concept of resiliency was firstly initiated from the engineering field and spread out into other fields, it was Thomas Tredgold who first introduced the concept in 1818 to highlight the strength of a timber made structure were beam was modified and deformed in order to be able to support heavy loads. In construction field resiliency is defined as, "the ability to absorb or avoid damage without suffering complete failure and is an objective of design, maintenance and restoration for buildings and infrastructure, as well as communities" (Sandia Labs, 2013).

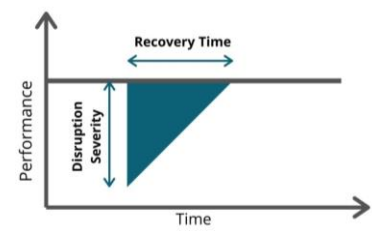


Fig.3: Resiliency Triangle  
Source: www.semanticscholar.org

### Disaster Resiliency Definition

The concept of disaster resiliency was originated and researched at the US by multidisciplinary and multi-hazard earthquake engineering research center in the late 90s. The research concluded a framework known as "4R" standing for—Robustness (ability to resist disruption and failure), Redundancy (the extent to which other alternative systems can continue to provide functionality and services), Resourcefulness (ability to mobilize alternative resources), and Rapidity (timely resolution of disaster-related challenges) (MCEER, 1990).

As it's not possible to predict all upcoming events, hence we cannot design for all, but a resilient structure or system should be able to withstand disasters with minimal damages during and after the event and be able to recover to its normal case or better in shortest time.

## 2.3 How Is Resilience Achieved

Today there are two dominant theories of resiliency achievement, first is the engineering theory which suggests that normally things function in a single state and resilience is the time needed to return to that original state, the other is the ecological theory which states that the resiliency of a system is the ability to absorb disruptive changes while still maintain the same relationship between state variables. Today, most of our structures' resiliency is based on the engineering theory, but if we look at nature, it is found that it functions even during the disruptions but more than that it uses some disturbances to develop new opportunities, therefore in order to increase current structures resiliency a biomimic approach to be adopted when designing future structures and systems (Shulze, 1996).

## 2.4 Introduction to Biomimicry

### Biomimicry Definition

Biomimicry is a complex word made up of two morphemes, "bio" from biology or nature, and "mimicry" from mimicking or copying the action of something, it's by then copying characteristic found in nature. The idea was first termed as biomimetics in 1950 by Otto Schmitt

who was an American biophysicist , followed by several terms such as biomorphism and bionics , all referring to the same idea .The current used term “biomimicry” was first coined by biologist Janine Benyus in 1997 in her book “Innovation Inspired by Nature”. During the past fifteen years there has been extensive interest in this approach motivated by biology scientists especially Steven Vogel and Julian Vincent. Julian Vincent defines the discipline as “the implementation of good design based on nature” (Pawlyn, 2016), while for Janine Benyus it is “the conscious emulation of nature’s genius” (Benyus, 2009). Biomimetic architecture is an approach that looks for problems solutions by copying principles found in nature that can contribute to solving these problems.

### Approaches to Biomimicry

Approaches for biomimicry as a design process could be categorized in two categories, first is “Design looking to biology” where the designer faces a certain problem and try to search for a solution that might be found in nature, second is “Biology influencing design” where the designer is already fascinated by a biological knowledge of a natural phenomenon or characteristics and then he searches for a problem in which this knowledge can contribute to. By examining the existing approaches in biomimicry, it appears that they lie under three levels; the organism, the behavior, and the ecosystem, under each of these categories five aspects could be defined as shown in table 2. These aspects are under Form”, “Material”, “Constructions”, “Process”, “and Function”. The design may be biomimetic for example in terms of what it looks like (form), what it is made out of (material), how it is made (construction), how it works (process) or what it is able to do (function) (Benyus, 2009).

Table 2: Biomimicry Approaches Levels Summary

Levels of Biomimicry				
Organism		Behavior	Ecosystem	
Form	Material	Construction	Process	Function

### Historical Background of Biomimicry in Architecture

Although bio inspired designs existed from ancient history mainly through using nature for decorative and spiritual goals , there was a shift towards using nature as a model for learning and mimicking functions , below are some important examples highlighting biomimicry approaches in architecture.

“Sagrada Familia- Barcelona” by Antonio Gaudi (1852-1926) Gaudi, in addition to the use of naturalistic aesthetic design, he also delved art nouveau architecture into structural biomimetics as he analyzed the function of natural forms and applied those elements to his architecture, the design mimics the natural weight distribution of trees, allowing each column to bear a greater load than a traditional column, as shown in Fig. 4.

During the period of modern architecture was also used to enhance structural designs, for example, the former zoology lecture hall at the university of Freiburg by Piere Nervi (1891-1979) was inspired by the internal geometry of bone tissue, optimized to resist external forces by creating a porous bone that efficiently maximizes its strength to weight ratio. Nervi maximized the complexity of his design by transforming and revolving simple forms; the sophistication of his geometry was never limited to the constructability of the structure, as shown in Fig.5. At the beginning of the 21st century a new path came along, alone that involves mimicking nature to resolve human problems. Nature is treated as a "Model, Measure, and Mentor" on a path toward



Fig.5: Former Zoology Lecture Hall

Source: [www.medium.com](http://www.medium.com)



Fig.4: Sagrada Familia (Under construction)

Branching Columns Nave  
Source: [www.steemit.com](http://www.steemit.com)

sustainability, an important example is the “Eden Project-Bodelva UK” by Nicholas Grimshaw(1939),as shown in Fig.6. The irregularity of the topography, combined with the uncertainty over the final ground levels made conventional, rectilinear solutions couldn’t be applied, the next challenge was to strive for the lightest possible structure, studying a whole series of natural examples – from carbon molecules and radiolarian through to pollen grains revealed that the most efficient way of structuring a spherical form is with a geodesic arrangement of pentagons and hexagons. The third challenge was to find efficient flexible material that is light and flexible at same time, Ethylene tetrafluoroethylene (ETFE) was used instead of glass. The final weight of the superstructure for the Humid Tropics Biome was less than the weight of the air inside. The Eden Project Biomes accommodate the existing form of the site with a minimum of excavation and suggest a more respectful reconciliation between humans and the natural world.



Fig 6 : Eden Project (2001)  
Hexagonal ETFE Bubbles  
Source:

Through examining previous architectural attempts in bio inspired designs we conclude that the Biomimicry Levels in Architecture are as follows:

- |            |                        |                      |              |
|------------|------------------------|----------------------|--------------|
| a- Concept | b- Process or behavior | c-Morphology or Form | d- Structure |
| e- Skin    | f- Material            | g-Expression         | h- Symbolism |

## 2.5 Efficient Structures Found in Nature

Natural library of organisms contains rich data base for ideas of structures that could be way more efficient and resilient than those found in our conventional building structures, such as trees, bamboos, bones, shells and many other load bearing or protective structures. The most important aspect of these structures is that they provide maximum strength with minimum energy and material, but with a special configuration. These characteristics are the result of natural enhancements due to the pressure of survival these structures encounter such as thermo regulating, avoiding predation and many other factors which contributed in refining their structures. There are many alternatives existing in nature one can use as an inspiration for creating more resilient structures, the most important step is to identify the design needs then choosing the proper model to imitate (Pawlyn, 2016).

## 2.6 Examples of Using Biomimicry in Improving Building’s Structures Resiliency

The literature review presents two examples to recognize the ways of architects in enhancing the Building’s structure resiliency through using biomimicry approach.

### 2.6.1 China world trade center 3b(2010) – Chaoyang, China – by Som Architects

The china world trade center is the second tallest building in Beijing located at Chaoyang District. Since the local environment is characterized by being placed on a seismic prone, SOM architects wanted to design the building to be earthquake resilient .In order to do so they search for a natural model which deals with the same issue

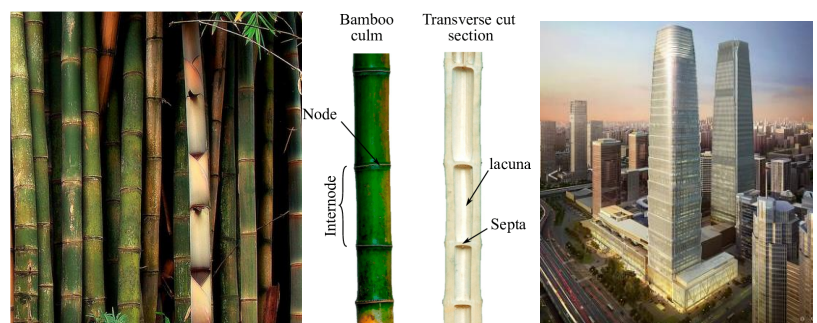


Fig.7: China World Trade Center 3B – Chaoyang - Structural Concept  
Source: WWW.SOM.COM

in a successful way, and it was the bamboo, due to its geometrical proportions and natural structural properties became their inspiration .It is made of stem containing nodes and

internodes marking the location of every new growth , stem changes in diameter where internodes are hollow , the maximum bending resistance is found at the point from the neutral axis of the stem .These characteristics of the bamboo load bearing process were perfect to enhance structural resiliency towards lateral loads, as shown in Fig.7 (Skidmore, Owings, and Merrill LLP., 2011).

### 2.6.2 Sendai Mediatheque (2001) – Sendai ,Japan – By Toyo Ito

Sendai Mediatheque is a library in Sendai, Miyagi Prefecture, Japan. Since Sendai area is characterized as a seismic region, team of Mediatheque though outside the box to create a structure that is responsive to its surroundings. Ito sought architectural inspiration from a source whose morphology was anything but static. The structure was made of four large corner columns in a form



Fig.8: Sendai Mediatheque - Japan - Structural Concept  
Source: ArchDaily

of lattice truss that changes at the basement level in order to ductile rigid frames below allowing in reducing the absorbent of earthquake, these proportion were inspired by the human body as for the heels, big toe and small toe all work together to maintain structural coherence, as shown in Fig. 8 (Pogonson, 2012).

## 2.7 Parameters to Analyze Biomimic Resilient Structures

Enhancing buildings structural resiliency includes a combination of approaches, one of is through the use of biomimicry. Biomimic approach varies based on the architect’s design approach, the context of the project, and the typology of the project, and most important based on the structural aspect aimed to be enhanced relative to the problem to be solved. All these points aim to give an idea about the architect’s consideration to be taken to choose what approach suits the project. As previously discussed, there are three biomimicry approaches; Organism level, where the architect mimic certain organism found in nature in terms of form or structure, Behavior level, where the architect mimics the behavior of a certain organism in terms of a natural process it encounters, Ecosystem level, where the architect mimics a combination of natural processes found in an ecosystem, it also possible for the architect to overlap between different approaches. After the architect choose what level to work with , it should be reflected in his design in one or more of the following aspects; Form, Material, Construction, Process, Function. In conclusion, to design a building structure with resiliency through biomimicry means to begin the design process by identifying carefully the typology of the building and it local context, then the common point of stresses and load applied due to normal use, in addition to a forecast for unforeseen disasters might happen based on local environment analysis, then digging in nature to find the best model that serves the design intentions and apply lessons learned into the project. Based on preceding points, certain parameters are concluded and listed in table 3.

Table 3: Parameters of Analysis of Biomimicry in Emphasizing Building’s Structures Resiliency

Project’s typology and context	Stress Points due to normal use	Potential non ordinary endangers	Building’s structural aspects need to be enhanced	Selected natural model to be analyzed and mimicked	Translation of natural principles into design decisions



### 3. METHODOLOGY

To achieve the main aim, this research concentrates on “Port of Beirut” as a local case study since it is suffering from a recent devastating disaster led to its own destruction in addition to the damage of more than thirty percent of the capital’s buildings. In order to attain so, this research uses various types of research methodology that can be summarized as four types. First, the inductive method is used through gathering data around the chosen case study; ‘Port of Beirut’, recognizing its strategic economic role’s development along history. Second, the field method, the author visited the site of ‘Port of Beirut’, taking live photographs, undertaking interviews with a sample of people living and working inside and near the port. Beside the interviews, a written questionnaire was distributed on this sample to recognize their point of views on the port’s existing problems before the 4<sup>th</sup> of august as well as the ones after and the possible ways to develop it. Third, the analytical method, the research analyzes results of interviews and the questionnaire. Finally, the deductive method, the research deduces a strategy of certain solutions to revive the damaged port in a more resilient way by restoring some of the lost functions and creating new possible functional interventions. The four research methodologies are presented through the research as follows.

#### 3.1 Introducing the Case Study Of ‘Port of Beirut’

Beirut, the capital of Lebanon, and the whole country is suffering nowadays after the blast that hit the “Port of Beirut” on the 4th of august 2020. The port of Beirut was the most vital sector as it was responsible for 80 % of goods importation, in addition to the revenues for the state treasury from transshipping and transit fees. This event deteriorated the existing social and economic situation aiding in increasing the number of poor and extreme poor in the country according to the world bank to 45 percent of the population Moreover, the explosion left the maritime supply chain fragmented as port of Beirut used to play a major center role as it lies on the Mediterranean coast as a crossroad of three continents of Asia, Africa and Europe and the gateway to the East as shown in Fig. 9.



Fig.9: A map showing Lebanon’s strategic location as well as “Port of Beirut” location.  
Source: [www.mapsofworld.com](http://www.mapsofworld.com)

### 3.2 City and Port History of Disasters

Beirut was destroyed and rebuilt seven times during its 5,000-year history as it was subjected to a range of hazards, most prominent ones are:

#### Earthquake

Situated in a seismic-prone zone, as shown in Fig. 10, Lebanon has experienced several earthquakes in the years, centuries, and decades. The most severe and famous one was on 551 AD were transformed Beirut including its port into ruins. The last major one was in 1759 measured seven which killed 40,000 people in Beirut.

#### Tsunami

Following the earthquake occurred on 551 AD, a devastating tsunami hit the coastal towns. Approximate number of people were reported death,

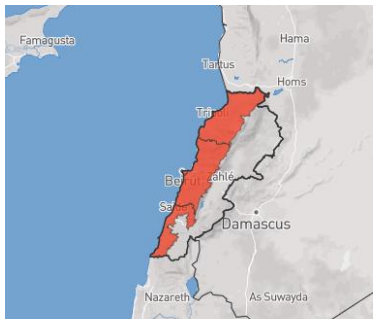


Fig.11: Lebanon Tsunami Risk Legend  
Source: www.thinkhazard.org

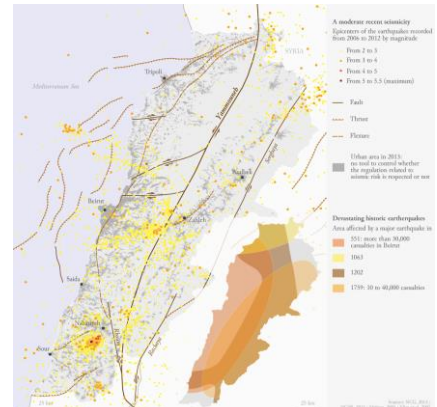


Fig.10: Lebanon Seismic Analysis Map  
Source: Atlas of Lebanon

30,000 for Beirut alone. According to the IPCC, the areas is in increasing risk of tsunami as global mean sea level rises, as shown in Fig. 11.



#### Port of Beirut Blast

On August 4, 2020, a big explosion destroyed the port of Beirut, Lebanon. More than 204 people died, about 6,000 were wounded, and at least 300,000 people were displaced. Losses from the blast are estimated to be at least \$10 to \$15 billion, as shown in Fig. 12.



Fig.12: Lebanon Tsunami Risk Legend  
Source: www.thinkhazard.org

### 3.3 Situation Comparison Before and After 4th August Explosion Original Port's Existing Building types and construction

The port of Beirut originally consists of five main parts ,as shown in Fig. 13 :

- 1- Container terminal : Containers mostly made up of steel
- 2- Silos : A huge circular structures made up of heavy reinforced concrete
- 3- Warehouses : Made up of steel
- 4- Free zone : Large steel warehouses and two stories concrete buildings

5- Passenger terminal : Small steel structure building

In addition to other zones for parkings , import/export inspection, security offices, maintenance garages, and other amenities of similar structures.

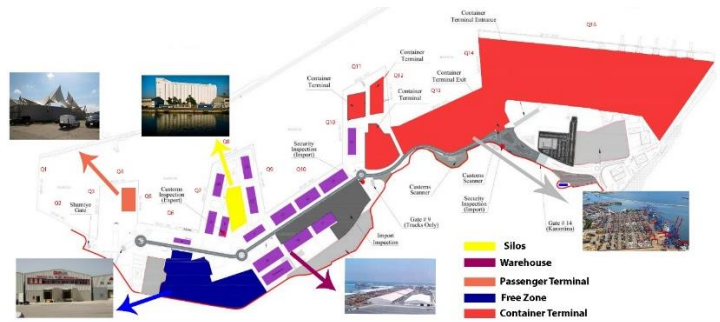


Fig.13: Port of Beirut main functions allocation with images.  
Source: www.unescwa.com

**Damages at port of Beirut**

The explosion destroyed all buildings and ware houses of different structural types in addition to huge damages to the silos buildings making them them all non functional and needed to be demolished or replaced. The only part that was slightly damaged is the northern part “container terminal” as it was far from the origin point of explosion. The explosion also caused severe damages in the city with approximate number of 8,000 damaged buildings of total economic losses estimated by 10 to 15 billion \$ according to the world bank, , as shown in Fig. 14&15.



Fig.14: Port of Beirut and surrounding’s damages  
Source: www.dar.com

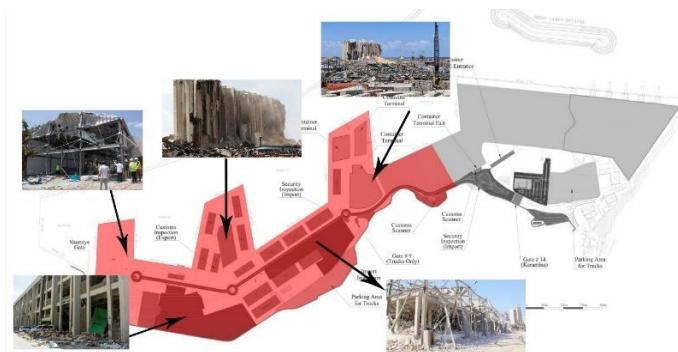


Fig.15: Major Port of Beirut Building’s Damages  
Source: www.portdebeyrouth.com

It is concluded from the damages detected , that in addition to the severity of the explosion , the structural weakness of port of Beirut buildings and many of surrounding public and private buildings which highlights the problem of the unpreparedness and unsuitability of the current designs and of buildings to face disasters.

**3.4 Identifying Problems of “Port of Beirut”**

Through examining the situation of buildings before the blast, all were built on a temporary basis with structural designs that does not take into consideration the potential disasters neither natural nor manmade ones , except for the grain silos which was the only building to survive the devastating event to an extent. After the explosion, many functions were



- a. What type of typology you believe should be the future of the selected area of port of Beirut?
- b. What change to building's designs should be addressed after what happened on 4<sup>th</sup> of August?
- c. How do you think applying biomimicry in future building's designs would be beneficial?

Answers were mostly similar; samples of these answers can be presented through the following quotations:

Ahmad Wardnai, 40 years old:

*"I am a concrete specialist working at a concrete batch plant at Biel facing the port of Beirut, my opinion is that the new part of port shall be interactive with people including new functions targeting its surroundings. New buildings and especially materials shall take into consideration new strengths in order to face strong stresses. In my opinion we could use biomimicry to create new sustainable material of strengths higher than the conventional ones used."*

Walid Jalakh, 50 years old:

*"I am a civil engineer working as a project manager for a huge construction project in Jimmayz district .I believe that residents surrounding the port should benefit from it and vice versa , the old situation of rupture should not be repeated. New structural designs shall include higher codes for several types of contingencies rather expected or unexpected ones. Biomimicry in structural design could benefit new design in achieving higher spans with less material and more resilient way."*

Hani Kabrit, 35 years old:

*"I am an architect having my own office at beirut central ditrict , I believe new port functions and typologies should take into consideration the economic and social circumstances in addition to the geopolitacal changes , which if we analyze them we conclude that the new port should include a touristic social interactive part. New building design should adress the aspect of resiliency and safety after such disaster in order to recover the feeling of belonging for citezens and their city;s port. II believe appying biomimicry in the new design would defiently help in achieveing the required resiliency in a sustaianble way."*

### 3.6.2 Questionnaire

A closed questionnaire was designed and distributed on 80 educated people of structural engineers, architects, and ecologists in the age group between 35 and 60 years old. Questions mentioned in this form were direct, simple, and specific as follows:

- a. What is your opinion in the level of existing built structural design resiliency in comparison to the potential ecological and manmade hazards?
- b. Could we have buildings able to withstand disasters such as port of Beirut blast?
- c. To what extent future's typology of port of Beirut will affect the new building's structural design?
- d. What is your opinion in incorporating nature's resiliency aspects in new building's designs?
- e. Are biologists and ecologists being involved in the design process?

After achieving the field methodology, the research analyzes results and findings of answers.

## 4. FINDINGS

### 4.1 Analysis of Interviews Results

The answers of the interviews were nearly the same and could be summarized in the following points:

- a- All highlighted the idea of feeling related to the port but not the opposite.
- b- All felt heartbroken after the recent explosion in addition to physical injuries.
- c- All agreed on reviving the port functions is the most immediate action to be taken.

### 4.2 Analysis of Questionnaire Results

Results are formulated through statistical charts and sketches that are based on specific cultural, social background, and economic level. Charts shown in Figs 19, 20, 21 represent the results.

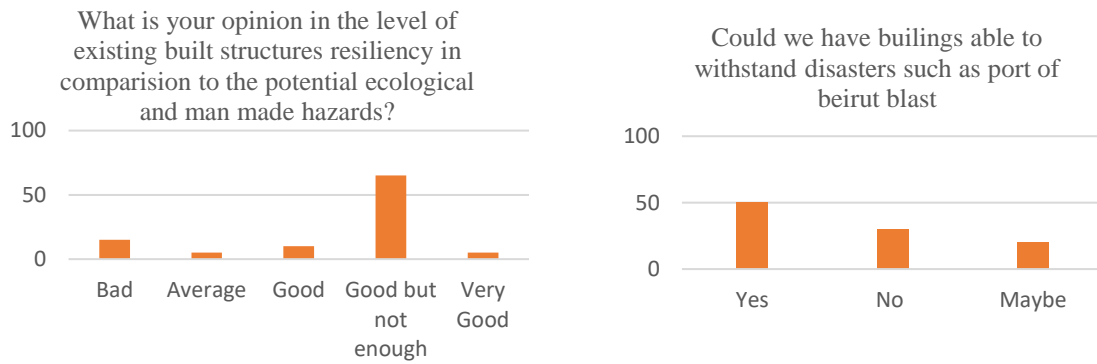


Fig.19: (a) On the left: most opinions of the existing built structures resiliency in comparison to potential hazards were “Good but not enough”; (b) On the right: most of visions state that it is possible to design buildings that can withstand such blast while the other majority stated it is not possible.

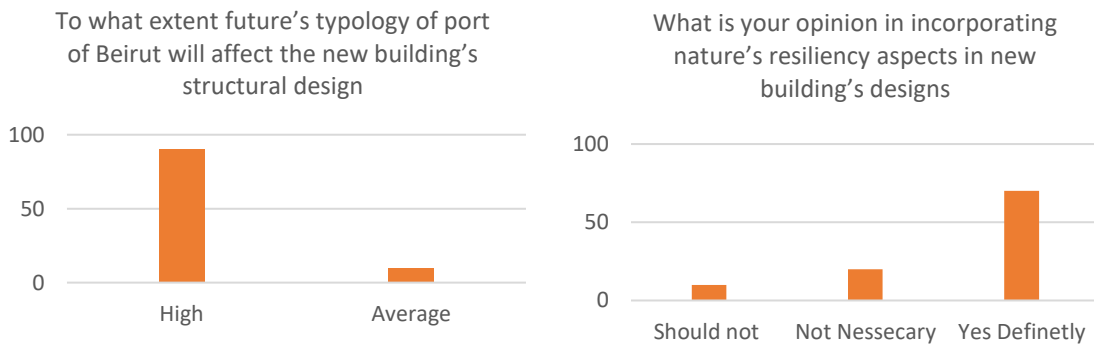
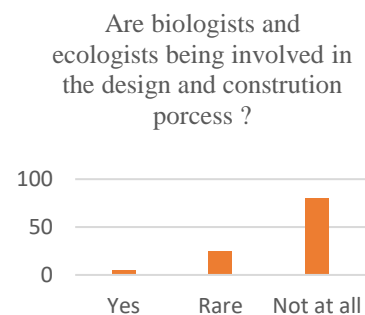


Fig.20: (a) On the left: most stated that the typologies of buildings affect the structural needs and systems to be designed; (b) On the right: most of opinions on incorporating nature's resiliency aspects were “Yes definitely”.

Fig. 21: Most stated that biologist and ecologists are not involved in design process



## DISCUSSION

The previous findings emphasized the importance of reviving the damaged port in a more resilient design approach to possibly withstand worst nightmare disasters resulting in a safer environment and increasing the feeling of security for the community and to the countries that shall use the port as a trading and transiting point.

Applying biomimicry in new structural designs would definitely aid in addressing higher level of resiliency which will be achieved in more sustainable way since nature is full of efficient structures and materials that our engineering field could benefit from.

Biomimicry could be applied on different types of buildings, but the approach is relative to the building typology and its structural needs which will lead us to the specific natural element that will be chosen in order to be mimicked and benefited from.

In case of “Port of Beirut”, this could be achieved through the following steps:

- New port’s typologies to be identified in order to identify the type of architectural spaces and respectively type of structures needed, in this case new touristic and social functions.
- Normal and potential hazards to be analyzed through understanding the ecology of site with the help of ecologists, in this case earthquakes, tsunamis and possible manmade disasters.
- In collaboration with biologists, natural models similar to these typologies and structures which deals successfully with the identified potential endangers to be searched for and analyzed for principles extraction.
- Principles might be found in natural models on different levels, morphology, structure, or behavior.
- Extracted principles to be translated into designs and engineering application on different building elements such as building structure, material, and skins.

## 5. CONCLUSIONS

If buildings become uninhabited due to earthquakes, or other devastating disasters, low carbon emission materials or other green building designing criteria do not matter at all, therefore every disaster should be a new launching point in the construction industry in which resiliency aspect to be taken into consideration as a main approach to achieve safe and sustainable cities. As discussed, nature is an important source of inspiration for such new designs since nature achieves resiliency in most sustainable and effective way. In order to achieve so, a collaboration between architects, structural engineers, ecologists and biologists is needed, therefore, construction industry should establish a research center where all mentioned participants collaborate on producing biomimic resilient designs for structures and materials. On the other hand, implementation of these systems requires significant adaptation. But using common engineering knowledge may not guarantee successful solutions. Hereby, new technology systems must be developed, then resilient structures and materials emulating nature can be developed easily and effectively.

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