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Research Article

Resilient Buildings: A Path towards Adaptability Climate Change Adaptation Strategies and Interventions for Buildings Resilience

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Abstract

Resilient Buildings present a significant amount of opportunity for climate mitigation. Since they are long-lived assets, they also present great challenges for adaptation to projected as well as unexpected climate change impacts. These impacts will have consequences for building design and fabric, as well as for people in and around buildings and for their health and well-being. It is essential that we identify the nature and extent of their vulnerabilities and resilience if they are to be adapted in a timely and effective manner. There are many assessment tools and methods being developed and used for identifying vulnerability and adaptive capacity of Buildings. However, there appears to be a knowledge and policy gap in the area of assessment of buildings in particular measuring their vulnerability and aiding in creating climate-adaptable and resilient buildings. This paper aims to examine the potential climate change effects on buildings and identify knowledge and Strategies for climate-adaptable buildings. Based on literature analysis, it provides a framework for the design and interventions for climate-adaptable buildings in terms of resilience.

Keywords: *Resilient buildings, Climate Change Adaptation, Building adaptability, design Strategies, interventions*

Introduction

The need for enhanced resiliency of buildings is becoming increasingly important nationally and globally and is a key component to economic, societal, and environmental viability. A 2011 United Nations report (Malay Dave *et al*., 2012) on disaster risk reduction identified that losses from disasters are rising faster than gains made through economic growth across all regions, threatening the economies of low- and middle-income countries as well as outpacing wealth gains across many of the world's more affluent nations. Recent major natural disasters and their impacts on national and global economies have heightened awareness and spurred activity to improve the resilience of buildings (Stephen S. Szoke *et al*., 2014).

A changing climate presents a challenge to the planners and designers of the built environment. It is important to bear in mind that small increases in temperature above normal levels can increase hazards dramatically, including the intensity of cyclone wind speeds, bushfires and flash flooding (Mark Snow *et al*., 2011) which can cause increase in building damage.

An architect who designs for climate change adaptation (CCA) recognizes that the nature of weather events is unlikely to remain the same throughout a building's lifetime.

Building professionals and designers will need to incorporate strategies that consider future climate change within their region. And need their own framework and tools for incorporating climate adaptation strategies in their own projects.

Effective urban planning and building design could play an important role in facilitating and development of a greater capacity for future resilience. The level of resilience of buildings and towns depend on the quality and performance of overall building system and materials not solely on the climate change adaptation of single element (Larissa Larsen *et al*, 2011).

Adapting building designs for climate change is about managing the unavoidable. While there is debate around what level of adaptation is needed, there is growing awareness that design practices need to take into account predictions of increased risk and intensity of extreme events, and the need for increased resilience through the design and construction of more robust, durable, long-lived, disaster resistant, safe and secure buildings (Stephen S. Szoke *et al*., 2014)

Resilient buildings: what is building resilience?

Resilience: The ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and

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efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions (IPCC, 2013).

Resilience is a term that emerged from the field of ecology in the 1970s, to describe the capacity of a system to maintain or recover functionality in the event of disruption or disturbance. It is applicable to Buildings because they are complex systems that are constantly adapting to changing circumstances.

Resilient Buildings: Building resilience describes the capacity of Buildings to function, so that Buildings are robust, durable, long-lived, disaster resistance, safe and secure no matter what stresses or shocks they encounter.

The notion of a resilient building becomes conceptually relevant when chronic stresses or sudden shocks threaten widespread disruption or the collapse of physical or social systems. The conceptual limitation of resilience is that it does not necessarily account for the power dynamics that are inherent in the way buildings function and cope with disruptions (Shaikh M. Ahsan, 2013).

In the field of Building Design, resilience has helped to bridge the gap between disaster risk reduction and climate change adaptation. Design can enhance the resilience of buildings through mandatory requirements that increase robustness, durability, longevity, disaster resistance, and safety.

Challenges of the future that buildings encounter

Resilience enables Buildings to evaluate their exposure to specific shocks and stresses, to develop a proactive and integrated strategy to address those challenges, and to respond to them more effectively.

Chronic Stresses: weaken the fabric of a Building on a day-to-day. Examples of these stresses include the impacts of both climate change and resources and energy scarcity.

Acute Shocks: are the sudden, sharp events that threaten a Building, including earthquakes, floods, and terrorist attacks (Nancy Kete, 2014).

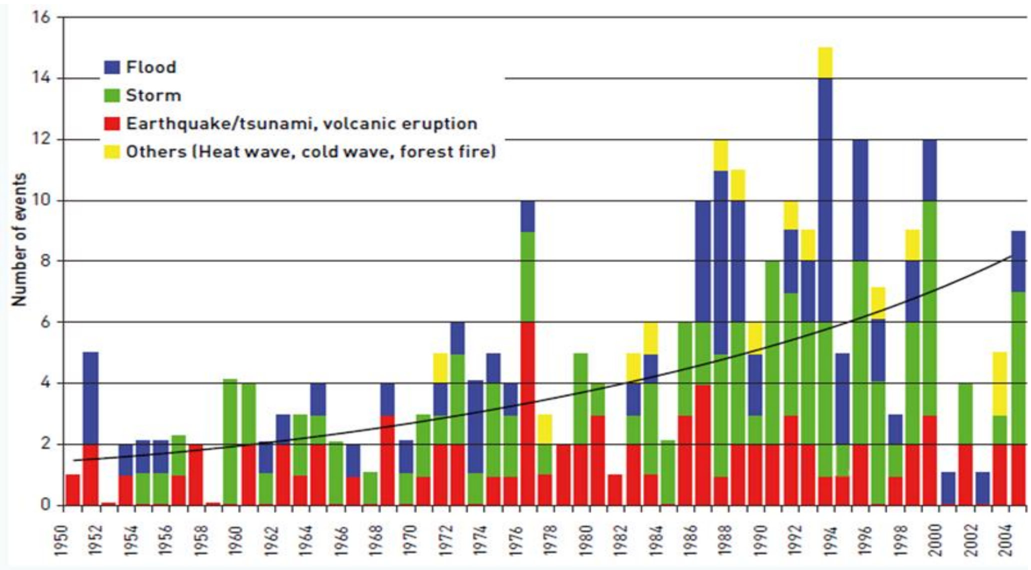

Figure 1: Weather – related catastrophes, 1950-2004 (Source: Munich RE, 2005)

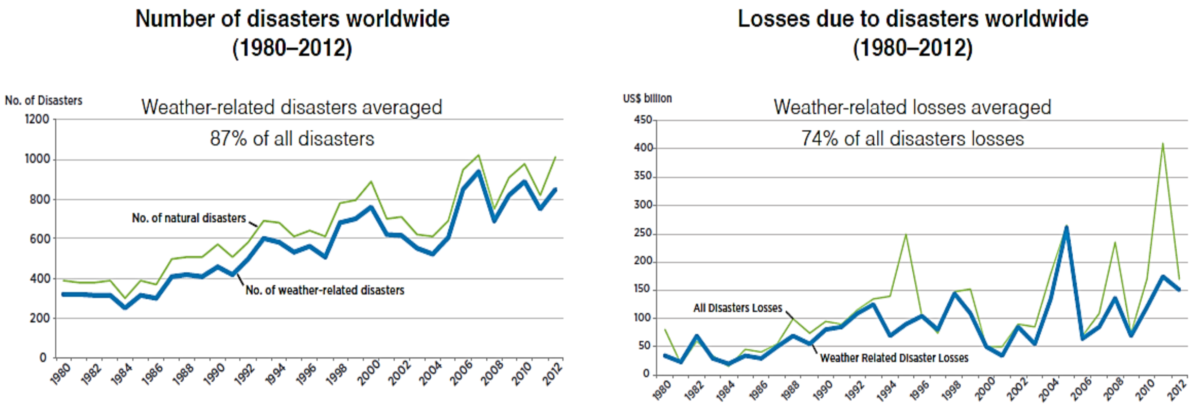

Figure 2: Total Number of Disasters and losses from 1980- 2012 (Source: Munich Re., 2013)

The challenges of a changing climate and its impact on the built environment

Weather and climate strongly influence human life in cities. Buildings will be affected by the impacts of climate change (Figure 1). This paper focus on a selection of climate challenges which are of particular relevance for buildings. Climate change's multiple impacts should be taken into account when planning and designing new developments and new buildings and when refurbishing and regeneration the existing buildings. These changes are higher temperatures, drier summers and drought, Sea temperature rise, increased precipitation, higher wind speeds, and their likely impacts are listed in below (ERC, 2010):

Higher temperatures impacts: Higher day time peaks, Higher night time lows, Higher winter temperatures, Enhanced urban heat island effect, Reduced air quality (e.g. increase in summer ozone episodes), Health implications, e.g. heat stress in frail and elderly.

Drier summers and drought impacts: Reduced water availability/shortages, reduced water quality, reduced soil moisture content/ increased subsidence, Changes in biodiversity, Health implications.

Sea temperature rise impacts: Sea level rise, increased sea surge height.

Increased precipitation impacts: More rainfall in winter, heavier rain in winter and summer/hail/snow, increased river flooding, increased urban drainage flooding, Health implications.

Higher wind speeds impacts: Increased storm damage, Outage of emergency, infrastructure and transportation services.

Impact of climate change on buildings

An architect who designs for climate change adaptation (CCA) recognizes that the nature of weather events is unlikely to remain the same throughout a building's lifetime. At the international scale, historical data and modelling by point to significant increases in mean annual temperatures which can increase hazards dramatically (Figure 2). The studies predicts an increased risk and intensity of extreme events and hazards such as bushfires, tropical cyclones, floods, hailstorms and droughts, which can cause increase in building damage, which are likely to result in considerable economic costs to Cities (Mark Snow *et al*., 2011).

Decisions can be (and are) made without accurate predictions of the future. It is better to use a range of plausible scenarios combining climate projections and other factors to explore outcomes and risks, rather than try to predict exact climate outcomes.

Potential effects of climate change on buildings

Rising temperature: Impact on external surfaces; thermal performance of building.

More intense rainfall: Greater intensity of runoff; issues of structural integrity; drainage; opportunities for capturing rainfall.

More frequent / Intense cyclones: Greater strain on building material fixtures, claddings and fasteners; greater wind loading requirements.

More frequent flooding: Sea level rise leading to coastal and inland flooding; more coastal salt spray; water damage to building contents; contamination from sewage, soil and mud; undermining of foundations.

More fire events: Total or partial fire damage; smoke and water damage.

More hail storms: Impact damage (mostly roofs, guttering, windows) and subsequent rain/moisture penetration.

Increased humidity: Mould; condensation; decreased thermal performance of building.

Decreased Humidity: Higher risk of fire.

What is adaptation?

Defining Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate (IPCC, 2007).

The United Nations Framework Convention on Climate Change (UNFCCC) uses two significant terms: mitigation, which is aimed at reducing emissions to minimize global warming or 'avoiding the unmanageable', and adaptation, which is 'managing the unavoidable' (GTZ/PIK, 2009).

The Intergovernmental Panel on Climate Change (IPCC 2008) defines four kinds of adaptation (IPCC, 2008):

Anticipatory (proactive) adaptation: Adaptation that takes place before actual climate change impacts occur. Such adaptation is a pre-emptive measure to prevent or to minimize potential climate change impacts. It weighs up the vulnerability of natural and man-made systems as well as the costs and benefits of action versus inaction.

Planned adaptation: Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to maintain or achieve a desired state.

Reactive adaptation: Adaptation that takes place after impacts of climate change: for instance when new building regulations follow a severe bushfire event.

Autonomous (spontaneous) adaptation: Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems.

Climate change adaptation

Within the built environment sector, climate change adaptation is often used simply to mean changes that can be made to the design or construction (less often the operation or use) of buildings and landscaping in order to cope with the consequences of one or more of the impacts of climate change (ERC, 2010).

Climate-adaptable buildings

Adaptation and adaptability are not new concepts in the built environment. Research shows that terms like 'Design for Adaptability', 'Adaptive Architecture', Climate Adaptive Building Shells', 'Adaptable House/ Housing' and 'Climate Adaptive/Adaptable/Adapted Buildings' refer to some of the concepts that are widely used in the built environment context. Most of these concepts have no direct reference to the need to adapt to the current or future climate change impacts; only one refers to climate in the sense of being climate responsive.

However, they all seem to offer insights into what would be the characteristics of a climate-adaptable building. With a wide range in the focus of these various concepts and definitions, it is also important to gain clarity on the definition of 'climate-adaptable buildings' in the context of climate change (Malay Dave *et al.*, 2012).

Adapting building designs for climate change is about managing the unavoidable. While there is debate around what level of adaptation is needed, there is growing awareness that design practices need to take into account predictions of increased risk and intensity of extreme events.

Adaptability in Buildings

Adaptation as Modification

Historically the term 'building adaptation' has been widely used to describe generic building modifications, ranging from small scale alterations to large scale additions. The adaptation as modification refers to adaptation in the built environment as modifications without necessarily linking the term with climate change (Malay Dave *et al.*, 2012).

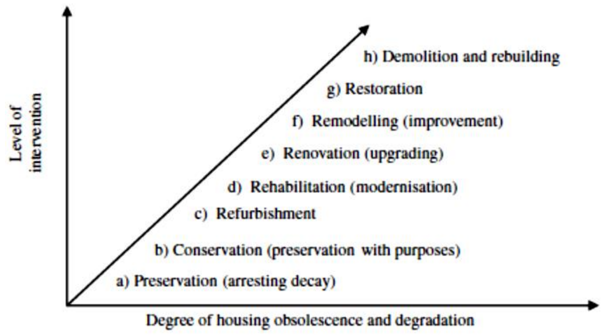

Figure 3: The range of building adaptation activities (Source: Teo & Lin, 2011)

Design for Adaptability

Inspired by the concern of sustainable use of materials and resources in the built environment this concept is aimed at maximizing the time that buildings, building components and materials remain in productive life. Graham (2005) explains 'Design for Adaptability' as a strategy used to avoid building obsolescence, and the associated environmental and cost impacts of resource consumption and material waste. (Graham, 2005).

This strategy looks at the concept of building as a system of constructed layers with different life spans, instead of as a static object. Designing for adaptability provides a framework for making strategic decisions about the right mix of flexibility and durability in buildings (Figure 3). A building that is designed for adaptability, according to this approach, would be designed:

With the end of the building life in mind

Considering it as a system of temporal layers and designed for accommodating the changes the building and its components would undergo during the entire lifecycle.

For long-life; or for long term durability and sustainability of the building and durable amenity for its occupants.

For loose-fit; or for spatial flexibility, structural flexibility, flexibility to assist materials and components change.

For deconstruction; or for independence between different layers or components with different functions to aid in disassembling for reuse, recycling or replacement.

Adaptable Architecture/Buildings

'Adaptable Architecture', 'Adaptable Buildings' or 'Buildings for Adaptability' are all concepts that are generally concerned with the flexibility in the function, physical form or experience in buildings along with a desire to develop systems for mass customization and pre-fabrication of building components. (Figure 4) illustrates different external stimuli for adaptable buildings and different forms of adaptability in this approach. Lelieveld, Voorbij & Poelman (2007) define Adaptable Architecture as *an architecture from which specific components can be changed in response to external stimuli, for example the user or environment*. (Lelieveld *et al.*, 2007)

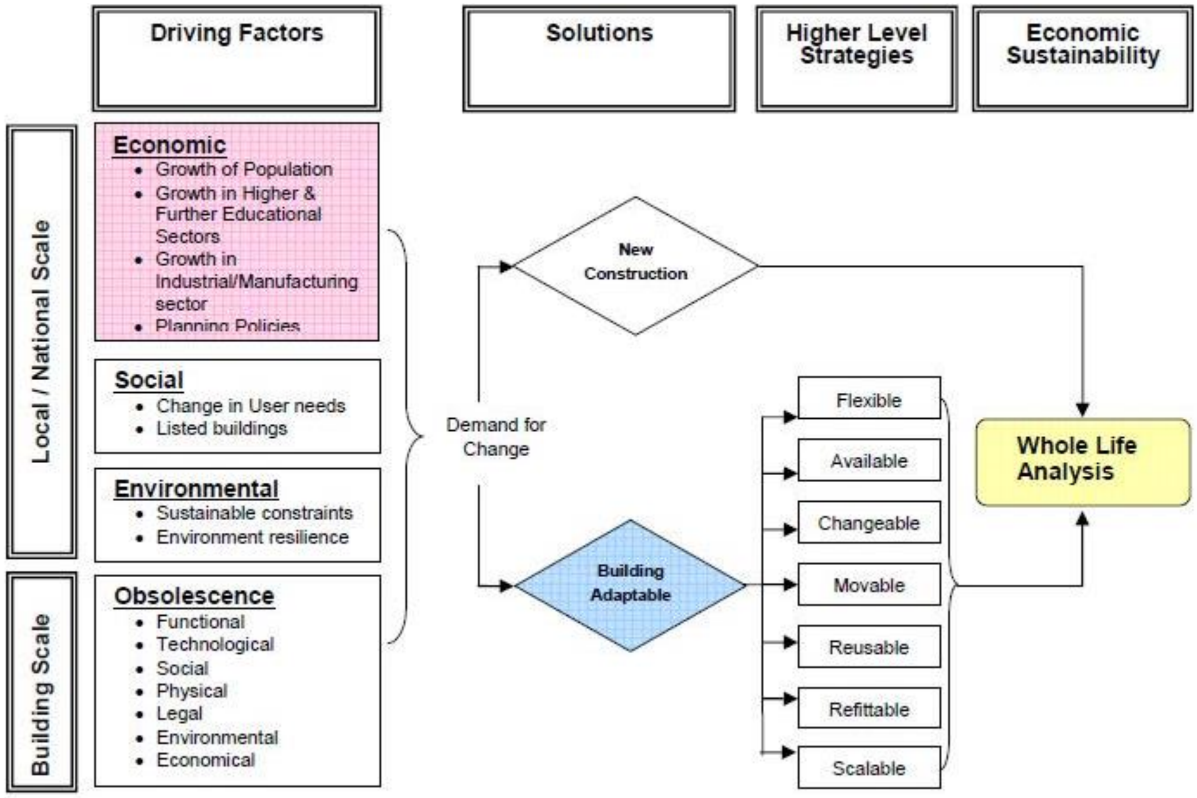

Figure 4: Adaptable buildings -Conceptual framework (Source: Manewa *et al*. 2009)

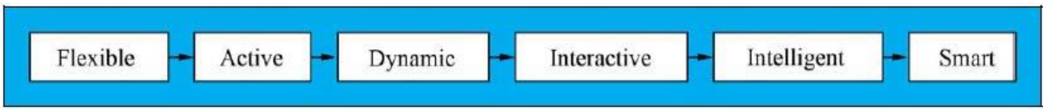

Figure 5: Levels of adaptation in order of sophistication (Source: Lelieveld, Voorbij & Poelman 2007)

Climate Adaptable / Adaptive / Adapted Buildings

Climate Adaptive Building Shells (CABS) is an expression of a concept, which is closely linked with many other terms, such as, active, dynamic, kinetic, intelligent, responsive and smart, that were generally categorised under the umbrella term of 'Adaptable Architecture/Buildings' (Figure 4). The concept of CABS specifically focuses on the building shell or building envelope and explores the possibilities of various forms of adaptability in this shell in response to changing climatologically boundary conditions or user's preferences (Figure 5).

Loonen *et al*. (2010) define CABS as a building shell that has the ability to repeatedly and reversibly change some of its functions, features or behaviour over time in response to changing performance requirements and variable boundary conditions. By doing this, the building shell improves overall building performance in terms of primary energy consumption while maintaining acceptable indoor environmental quality (Loonen *et al*. 2010).

Loonen (2010) discusses two design strategies that contribute to the system's ability to handle change: robustness and flexibility; and argues that the conventional buildings have to rely on their robustness to cope with real-time changes in the context, while the CABS use their real-time flexibility to change their function, features or behaviour in response to the external change in addition to being able to respond to changing user preferences.

The majority of the recommendations apply to building core and shell and address building components and systems that can be difficult or cost prohibitive to upgrade or strengthen once the building is occupied. While each of the criteria discussed may satisfy multiple aspects of enhanced resilience, **they are presented in these main categories:**

Service Life - Design service life criteria addressing durability, longevity, re-use, and adaptability.
Structural Components-Enhanced structural load resistance addressing fire, flooding, frost heave, snow loads, wind loads, seismic loads, and storm shelters in high wind areas.

Fire Protection Components - Enhanced protection related to internal structure fires addressing automatic sprinkler systems, fire containment, and potentially hazardous conditions created where recyclables are collected and stored.

Interior Components – Increased robustness that also provides enhanced acoustical comfort and reduction of damage where moisture may be present.

Exterior Components - Enhanced protection related to exterior finishes and systems used to clad the building – addressing wind, impact, fire, rodent infestation, and radon entry resistance.

Benefits of Building Adaptation

There are many benefits related to enhancing the resilience of buildings. In addition to long-term environmental benefits, other benefits are better buildings for occupant safety, comfort, and productivity; property protection – both building and building contents; economic benefits for the building occupants, owners, and the community; and societal benefits related to operational continuity for the community. Sufficiently robust and durable resilient buildings (Stephen S. Szoke *et al*., 2014):

- Minimize the amount of resources required for routine maintenance, repair, and replacement over the life of the building, with long-term benefits for subsequent owners and occupants.
- Provide enhanced safety and security for improved occupant comfort and productivity.
- Increase design service lives.
- Enhance the operational continuity of the community in which they are built.
- Are adaptable for future use and re-purposing to minimize long-term environmental impacts involved with replacement, removal, disposal, and reconstruction.
- Attract and retain businesses and residents.

When disaster strikes, more resilient buildings reduce the:

- Time for communities to recover after disasters.
- Demand on emergency response personnel.
- Expenditures required for emergency response.
- Risk of injury or death for emergency responders.
- Owner, occupant, and community expenditures for disaster recovery.
- Amount of resources required for disaster relief.
- Amount of damage and contaminated materials and contents to be disposed in landfills or by incineration.

Climate adaptive strategies for building design

Building flexibility must be merged into the design process to increase building capacity for the unexpected risks which makes investment decisions robust to most possible changes in climate conditions. This may include no-regret strategies that bring benefits even in the absence of future climate change, e.g. strengthening tile fixtures securely to a roof to avoid wind damage, or polishing or tiling a concrete ground floor to allow quick recovery after a flood (Patricia H. Longstaff, 2013). Beyond these measures, designers should be researching localized risks of climate change and preparing their buildings for the predicted hazards (Mark Snow *et al*., 2011) which may include:

- Increasing temperatures
- Coastal storm surges and inundation
- Flooding
- Tropical cyclones
- Intensified downpours
- Hail events

Incorporating climate adaptation strategies into new buildings

Resilient buildings professionals can integrate climate adaptation strategies into a project by using the following four step process (Larissa Larsen *et al*, 2011):

- Understand regional impacts: Identify climate impacts for the projects region
- Modify performance goals: Incorporate possible impacts into performance goals for the building.
- Determine the range of effects on the local built environment: Refine regional impacts to a smaller scale: anticipate how climate changes are likely to manifest in the local environment: present design team with a range of possible scenarios.
- Select a combination of no-regrets and resilient adaptation strategies: Choose strategies that enable the project to achieve and maintain performance goal under all possible futures, for the expected life of the project.

Incorporating climate adaptation strategies into existing buildings

Green Building and climate adaptation strategies must be applied to existing buildings as well as new buildings projects. The steps below describe how a project team can integrate adaptation strategies to existing buildings and sites (P.H. Longstaff, *et al*., 2010).

Understand regional impacts: Identify climate impacts for the building's region.

Evaluate current operation and maintenance targets: understand how the maintenance and operations perform under current peak climate conditions.

Conduct a scenario analysis: analyze how the building will respond to projected climate impacts.

Modelling different system options under variety of climatic conditions.

Climate Adaptation strategies for buildings to counter increasing temperatures

Passive design strategies have the double benefit of countering increasing temperatures without undermining mitigation efforts. The fundamentals of passive design are (Tyler S, Moench M. 2012):

- Thermal mass to reduce the internal temperature variation.
- Insulation and the use of low emissivity roofing paints and high performance glazing to reduce the rate of heat transfer through building structures.
- External shading of vulnerable building surfaces, and strategic siting of deciduous vegetation.
- Cross ventilation and mixed-mode design to cool internal spaces (ensuring insect-repellent screens are also used).
- There are significant opportunities for the deployment of systems that use renewable energy sources, as well as highly energy-efficient technologies, including:
- Green roof and roof design technology.
- Photovoltaic glazing.
- Low heat producing lighting, equipment and plant.
- Photovoltaic, solar, biomass, and wind-powered.
- Cooling technology.
- Co-generation technologies (including waste heat capture technology).

Climate Adaptation strategies for buildings to counter Coastal Storm Surges and Inundation

With over 85 per cent of the population living in coastal regions, strategies to reduce the threat of coastal storm surge and inundation are of critical importance. Three overarching strategies underpin the designing of higher resilience from storm surge and inundation:

- Protect land infrastructure and buildings from coastal storm surges and inundation by constructing hard structures (such as seawalls) and using soft measures (such as beach nourishment) so that existing land occupation can be maintained.
- Accommodate surges and inundation, e.g. by elevating buildings on piles and designing the building foundation and any portions subject to flooding to withstand design flood conditions.
- Retreat from coastal areas under significant threat.
- Generally, designers should be guided by local government risk assessments and planning controls.

Climate Adaptation strategies for buildings to counter Flooding

Flooding events around the world produced a heightened sense of the need to better plan and design buildings and infrastructure to reduce vulnerability to flooding risk.

Building codes establish the minimum standards required for a given locations and circumstances and are typically increased following an extreme events (EEA Report, 2012).

Architects should assess whether these provide sufficient protection against climate change impacts anticipated for the lifetime of the building. Given that individuals can pay off the higher construction costs over the life of a mortgage, building design measures that can adapt to a certain level of flooding can be a cost-effective and affordable approach.

Besides siting, there are many options available to reduce the flooding risk and damage potential when designing and constructing new buildings. In order of priority, these are:

- Exceed minimum floor levels.
- Consider multi-storey construction.
- Design and construct buildings for flooding occurrences.
- Use water-resistant materials (see Table 1).
- Design to ensure water can easily escape once flooding has subsided (especially vital for cellars and foundations).
- Install essential vulnerable equipment as high as possible.
- Raise flood awareness and preparedness with building occupants, including designing and providing information about access routes.
- For existing buildings, the recommendations are similar to those for new buildings (Gething, B 2010):
- Raise or move the building.
- Build a second or multiple stories and use the lower storey as non-living or 'non-productive' space.
- Replace cladding, flooring, and linings with water resistant materials.
- Move services (hot water, meter board) above flood levels.
- Build a levee or flood wall around the building.
- Raise flood awareness and preparedness with building occupants.

Exceeding the minimum floor level clearance requirements for the area can substantially reduce the risk of flood damage.

The water-resistant materials listed in (Table 1) are better able to withstand direct contact with flood waters for more than 72 hours, and are more likely to require only a low-cost cosmetic repair, such as repainting.

Table 1: Water-resistance of some building materials (Source: Mark Snow *et al*., 2011)

	Water resistant	Non-water resistant
Insulation	Closed cell foam (polystyrene polyurethane)	Fiber glass, mineral wool. wool, cellulose foil
Floors	Concrete (bare or coated) Floorboards, durable or treated timber Concrete or clay tile	Particleboard. MDF. plywood Ceramic tile
Floors	Concrete block Fiber-cement Durable or treated timber	Plasterboard, Plywood Hardboard Softwood Carpet or vinyl Particleboard

Interventions for building adaptation to climate change for more resilient buildings

Climate change adaptation interventions can be categorised in different ways. This Part depends on the classifications used in the EU's White Paper on adapting to climate change (EC, 2009).

Grey infrastructure approaches: correspond to physical interventions or construction measures and materials and using engineering services to make buildings and infrastructure more resilient and capable of withstanding extreme events.

Green infrastructure approaches: contribute to the increase of ecosystems resilience and can halt biodiversity loss, degradation of ecosystem and restore water cycles. At the same time, green infrastructure uses the functions and services provided by the ecosystems to achieve a more cost effective and sometimes more feasible adaptation solution than grey infrastructure.

Soft approaches: correspond to design and application of policies and procedures and employing, inter alia, land-use controls, information dissemination and economic incentives to reduce vulnerability, encourage adaptive behavior or avoid maladaptation (UNECE, 2009).

Due to the expected increase in the number of hot days and heat waves, it is important for Buildings to adapt with the high temperatures and adaptation to climate change can be reached through:

- Higher day time peaks/Urban Heat Island Effect:
- Employ building shape and orientation to provide solar control
- Employ cool or reflective building materials on roofs and facades
- Use green or brown roofs and green walls to regulate temperature
- Provide external solar shading
- Install (controllable, secure) natural (night time) ventilation, integrated with security
- Increase thermal capacity of construction
- Increase insulation and airtightness of building envelope
- Reduce internal heat gains through correct location and use of energy efficient appliances and lighting
- Use ground water source heat exchange for cooling (heating)
- Where mechanical air handling units installed, ensure don't discharge into frequented external spaces
- Allow for appropriate in-house storage of composting, waste and recycling in hot weather
- plan for long term management and maintenance of adaptation measures
- Monitor and evaluate performance (internal conditions and external spaces)
- Higher night time Lows
- Install (controllable, secure) natural (night time) ventilation/cooling, integrated with security
- Higher winter temperatures
- Eliminate/reduce sizing of heating systems
- Changes in biodiversity
- Use green/brown roofs to provide habitats
- Bird boxes
- Swales in streets
- Ensure buildings do not obstruct flight paths, corridors or networks
- Reduced water availability/ shortages
- Design planting and landscaping to provide summer shading for building
- Install water efficient fixtures, fitting, and appliances
- Use rainwater harvesting including water butts
- Use greywater recycling
- Reduced water quality
- Design in accordance with SUDS Design Manual to preventing water pollution underlying water, particularly underlying water
- Where mains sewer not available, select sewage treatments that comply with European standards
- For industrial developments, ensure drainage from contaminated areas is directed to foul sewer
- Reduced soil moisture content/ increased subsidence
- Design foundations and structure to cope with increased subsidence on shrinking and swelling soils and in proximity to vegetation
- Sea level rise
- Avoid development in flood risk locations
- Provide temporary/permanent flooding defenses for at risk properties
- Fit (removable) flood defense products to properties
- Design building and use materials that can withstand flooding
- Locate electrical services above flood levels
- Employ flood-resilient materials
- Wet proof unprotectable buildings
- Prevent back up of drains into building

- Increased sea surge height
- Maximize density of development in non-flood risk areas (bearing in mind other climate change challenges such as higher temperatures)
- Provide temporary/permanent flooding defenses for at risk properties
- Fit (removable) flood defense products to properties
- Locate electrical services above flood levels
- Employ flood-resilient materials
- Wet proof unprotectable buildings
- Prevent back up of drains into building
- Heavier (driving) rain/hail/snow
- Consider prevailing wind and driving rain when planning layout
- Install wider gutters
- Upgrade rainwater disposal systems
- Employ sustainable urban drainage systems
- Provide green and blue cover
- Detail external envelope to withstand driving rain
- Prevent back up of drains into building
- Install mechanical or UV light systems to prevent damp and mould growth
- Increased river flooding
- Maximize density of development in non-flood risk areas
- Use soft defenses as buffer as part of green/blue landscaping
- Open water courses across site for amenity and flood absorption
- Provide emergency access points
- Provide temporary/permanent flooding defenses for at risk properties
- Fit (removable) flood defense products to properties
- Locate electrical services above flood levels
- Wet proof unprotectable buildings
- Install mechanical or UV light systems to prevent damp and mould growth
- Increased urban drainage flooding
- Minimize peak run-off and annual surface water run-off rates
- Use sustainable urban drainage systems (permeable paving attenuation systems, filter drains, ponds, wetlands)
- Prevent drainage back-up
- Increased storm damage
- Detail external envelope to increased wind velocity and withstand driving rain
- Employ resilient ducting, overhead cabling, drainage and other services
- Lost emergency, and other services
- Provide local (standby) generation

International examples for climate adaptable buildings

This part will present examples of climate change adaptable buildings that was designed and constructed to encounter the extreme climate change, these examples are:

The Butterfield Park Business and Innovation Centre in Luton – UK

The Butterfield Park Business and Innovation Centre in Luton incorporates overhangs and external shading with an innovative ventilation system using earth ducts, which reduces energy consumption by up to 75%, regulates air temperature and guarantees excellent air quality (Figure 6). Fresh air is drawn through earth ducts below the ground, effectively using the earth as a source of heat in winter and of cooling in summer, without the need for air conditioning. The fresh air is supplied into the buildings via a pressurized floor plenum. The building achieved a BREEAM Excellent, an 'A' rating under the European Energy Performance of Buildings Directive, and was given a Green Apple Award for achieving the highest standards in environmental sustainability (ERC, 2010).

Figure 6: The Butterfield Park Business and Innovation Centre in Luton incorporates overhangs and external shading. (Source: ERC, 2010)

Stevenage Borough Council offices, UK

As part of the EU-funded REVIVAL project 30, thermal mass and night cooling have been exploited in the refurbishment of offices for Stevenage Borough Council to reduce daytime temperatures. A nighttime cooling system uses the hidden mass of the building. During summer, cool outside air is introduced into the offices by window fans at night (Figure 7).

Ceiling fans circulate this air under the floor duct to enable cooling to be stored in its thermal mass. Next day, ceiling fans release stored cooling. Monitoring before and after indicate that a reduction of about 5 K in internal temperatures has been achieved relative to ambient temperatures. Areas with night ventilation are also reported as fresher in the morning (http://www.breeam.org).

Figure 7: Stevenage Borough Council offices uses thermal mass and night cooling. (Source: www.breeam.org)

Lion House, Alnwick, UK

Defra's Estates Division wanted its new office accommodation, Lion House, Alnwick, to be an exemplar of sustainable development. The design maximized use of natural daylight, with the build orientation and shading also enabling the use of winter solar gains; Natural cross-ventilation is predominantly used for general office spaces, with capability for mechanical displacement ventilation to offset seasonal variations(Figure 8). A ceiling mounted 'red-green' system advises occupants when windows may be open to aid natural ventilation and when mechanical ventilation is operating. Exposed thermal mass allows passive night cooling in order to maintain optimum internal temperatures during warmer times of the year (www.lucid-project.org).

Figure 8: Lion House, Alnwick; an exemplar of sustainable development (Source: www.lucid-project.org)

Omega Centre for Sustainable Living New York

Located in Rhinebeck, New York, the Omega Center provides innovative educational experiences that awaken the best in the human spirit (Figure 9). The Omega Center is an environmental education center and wastewater filtration facility that is designed to use the treated water for garden irrigation and in a greywater recovery system (Ash, A, 2014).

- Site: reuse of solid debris landfill and fill removed and resold
- Materials: Embodied carbon footprint = -1,387 metric tons
- Water: annual water use all harvested on-site and all grey and black water treated on-site
- Energy: generate almost 40,000 kWh per year via solar panels which is more than their 37,190 kWh/yr needs
- Health: ducts protected during construction, low-VOC material selection throughout, and a green cleaning program

Figure 9: The Omega Center for Sustainable Living is one of three certified resilient buildings in the world. *(Source:* Ash, A, 2010)

Shanghai Hongqiao Airport Flower Building/ MVRDV,China

Hongqiao Central Business District achieved China's green building label three stars of the highest ranking. Sustainable building features include high-performance insulation, optimized architectural form, shaded spaces, natural ventilation, rainwater harvesting, permeable pavement, convenient public transport and reduced urban heat island effects (Figure 10). All 10 buildings will also provide roof greening as a habitat for local species. MVRDV has finished the construction of three projects in China and Hong Kong, all were completed by the end of 2015 (www.livingroofs.org).

Figure 10: Shanghai Hongqiao Airport Flower Building; an exemplar of adapable, green and resilient buildings (Source: www.livingroofs.org)

Conclusion

Through what has been dealt with in this paper, the following can be concluded:

- The need for enhanced resiliency of buildings is becoming increasingly important nationally and globally and is a key component to economic, societal, and environmental viability.
- Building flexibility must be merged into the design process to increase building capacity for the unexpected risks which makes investment decisions robust to most possible changes in climate conditions.
- Regional spatial planning and urban design can provide solutions that make our communities less vulnerable to climate change.
- Orientation, along with window design and careful planning of a building's internal layout, can be designed to optimize solar gain in order to reduce the need for winter heating.
- The use of reflective materials on the external surfaces of buildings or in hard landscaping to lessen the impact of climate change is based on the albedo effect. This is the extent to which a material reflects light, e.g. from the sun, with a range of possible values from 0 (dark) to 1 (bright).
- Replacing dark roofs and pavements with lighter-colored ones increases urban albedo.
- Adapting buildings to the impact of climate change requires an integrated approach to environmental design and to the performance of buildings in use.
- Green roofs, and green areas on façades of buildings called living walls, can offer a wide range of benefits, including reduced pollution, attenuation of rainwater run-off, improved thermal stability and energy conservation, reduced maintenance, enhanced air quality, In addition, they are attractive to look at and by greening living environments can enhance the quality of life of residents.
- Brown roofs, also known as bio-diverse roofs, are used to mitigate the loss of habitat by covering the flat roofs of new developments with a layer of locally sourced material.
- Heating and cooling requirements are driven by building type, internal loads and building envelope design - and by climate.

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