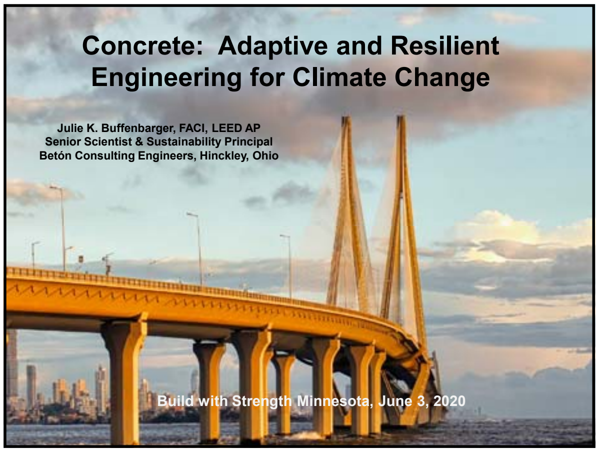
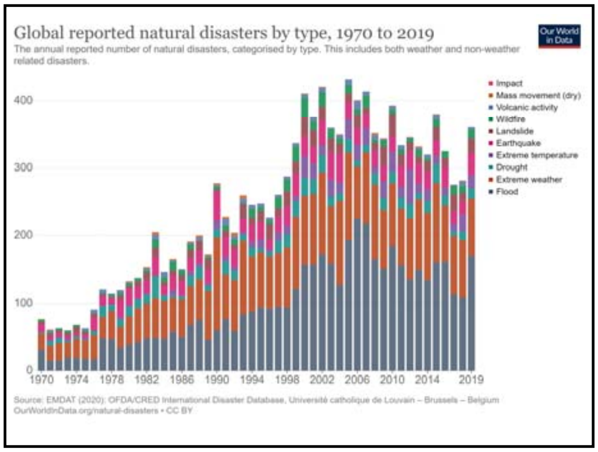
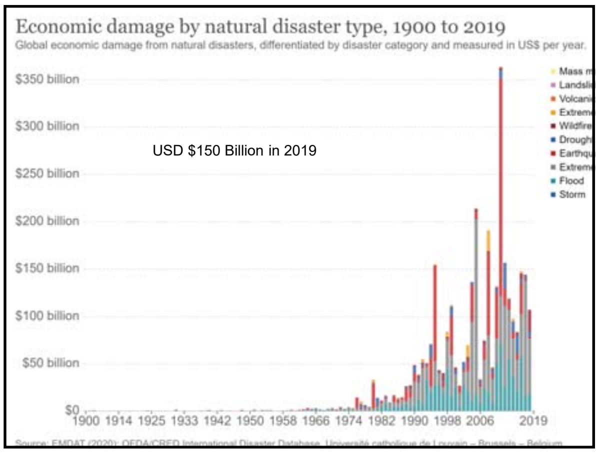


Designing for Sustainability & Resilience

ENVIRONMENTAL	SOCIAL
Ecology & Biodiversity	Community Interaction
Landscape	Community Liveability
Stormwater Impacts	Human Health Impacts
Construction Waste Management	Historic & Cultural Preservation
Material Use	Scenic & Natural Qualities
Energy & Carbon	Safety
Reduce, Recyle & Reuse	Equity
Reduced Energy & Emissions	Stakeholder Involvement
Noise Pollution	Transportation Impacts

ECONOMIC	RESILIENCE
Life Cycle Costs	Multi-Hazard/Climate Risk Assessment
Project Management	Site Planning - Land Use & Landscape
Financial Sustainability	Infrastructure Resilience & Protection
Economic Analysis	Environmental Protection
Safety Programs	Ecosystem Services
Land Use	Vital Facilities & Functions
Operation & Management Systems	Superior Functional Peformance
Bridge Management Systems	Beyond Life & Code Safety Standards
Energy Efficiency	Passive Survivability





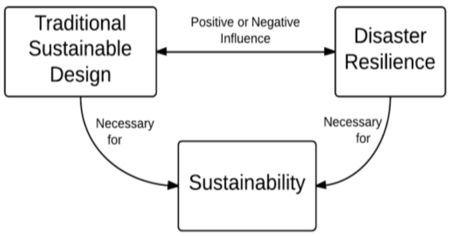
Natural and Manmade Disasters

- **Measurable Global Impacts**
  - Loss of Lives
  - Damage to Infrastructure
  - Economic Costs
    - US$ 1.19 trillion from 2010-2019*

- **Implications beyond Measurable Impacts**
  - Loss of Elements of Social Capital
    - Identity
    - Culture
    - Historical
    - Community

* Aon, *Weather, Climate & Catastrophe Insight: 2019 Annual Report*, 2019

Traditional Sustainable Design, Disaster Resilience and Sustainability

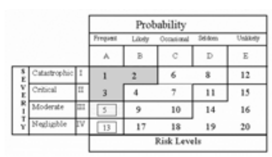


SEI Sustainability Committee

Sustainability vs. Resilience

Typical sustainability assessments usually concern "ordinary events" that have relatively high probabilities and low impacts (e.g., day-to-day maintenance and operations).

Resilience assessments usually concern "extraordinary events" that have relatively low probabilities and high impacts (e.g., the possible loss of a building in an earthquake).

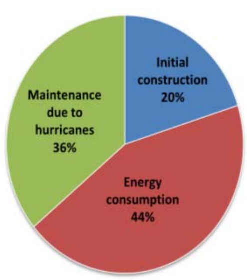


Rodriguez and Perez, 2014

Quantifying Life Cycle Costing & Resilience

How to quantify and incorporate different performance metrics into the process of comparative cost assessment.

- Resilience of the built system
- Resilience to the hazard
- Frequency and intensity of hazard?
  - Probability of Risks



What is the Risk?

A measure of the expected loss due to uncertainty.

(Risk) = (Hazard) x (Vulnerability) x (Consequences)

1. **Hazard – probability that it will occur.**
2. **Vulnerability – probability of damage or loss given the hazard**
3. **Consequences – loss or consequence if the hazard is a successful in causing damage.**

For climate adaptation it can be re-expressed as:

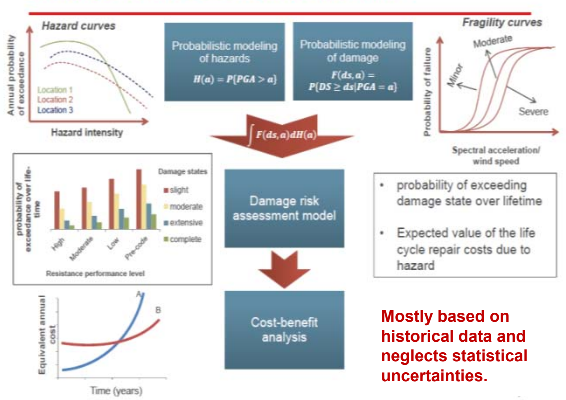
$$E(L) = \Sigma \{Pr(C)Pr(H|C)\}_{Hazard} * \{Pr(D|H)Pr(L|D)\}_{vulerability} * \{L\}_{loss}$$

$$E_{adapt}(L) = \Sigma\,(1-\Delta R)E(L) - \Delta B$$

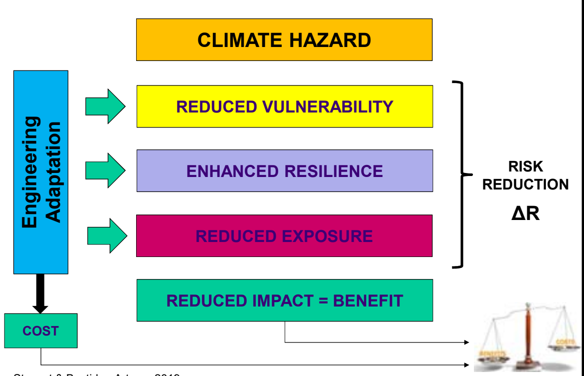
(Reduction of Risk caused by climate adaptation)

L = Loss, E=Economic, B=Benefit, Pr(D|H) = Fragility

Damage risk assessment framework



Risk Assessment: A Balance

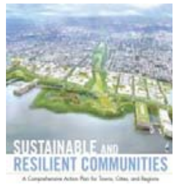


Stewart & Bastidas-Artega, 2019

Functional and Community Resilience

Resilient communities

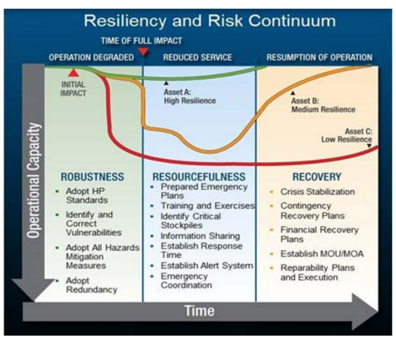
- Minimize damage and losses of property, environment and lives
- *Quickly return citizens to work, reopen businesses, and restore other essential services.*



Functional Resilience

- A structure's *durability and competence to maintain its integrity and its function restored.*
  - Climate-related and Natural Disaster Stresses
  - Terrorism
  - Day-to-Day Stresses

Criticality of Structure



Operational Capacity After Disaster:

- Bounce Back
- Bounce Forward
- Enhanced Capacity by "Building Back Better"

M. Kennett, Resilient Buildings Workshop, November 2012.

Investing in Resilience

<u>Exceeding minimum design requirement</u> in codes for enhanced resilience provides…

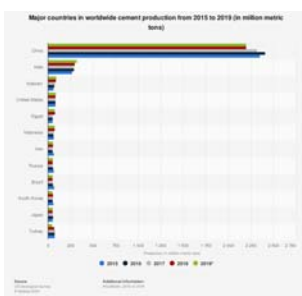
- Societal Benefits by averting
  - 4000 PTSD
  - 1 Million non-fatal injuries
  - 87,000 long-term jobs
  - 600 Deaths
- Environmental Benefits by enhancing
  - 1% increase in utilization of construction material
- Economic Benefits in saving
  - $1.00 invested in hazard mitigation strategies saves $6.00 in disaster losses

How Can the Cement, Concrete and Design Industry Influence this Model?

Cement and Concrete Demand

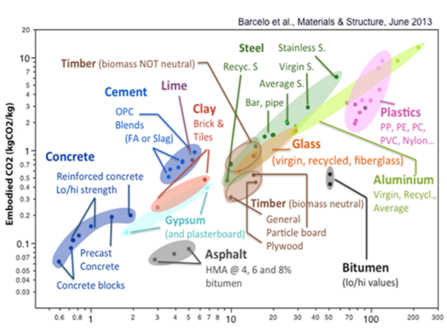
Global cement demand grew from 1.2 Gt/yr in 1990 to 4.2 Gt/yr in 2015 (approximately 5% year).

Projected growth for 2050 by 7.5 – 25%*



IEA Cement Road map, UN Environment, Chatham House

Embodied Energy – CO_2



Concrete Manufacturing and CO_2 Production

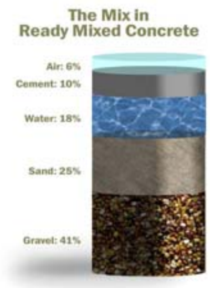
Small percentage embodied energy in concrete
- 170-500 lb/yd3 (100-300 kg/m^3) of embodied CO_2

Concrete uses 7% and 15% cement by volume

That is 5% to 13% of the weight of concrete

CO_2 reabsorbed into concrete through carbonation

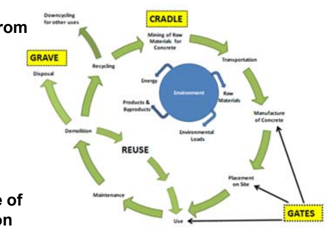
33% to 57% of CO_2 emitted from calcination is reabsorbed through carbonation over 100-year life



Material Efficiency & Recycling

The basic principle of material efficiency is to use less material to meet the same transport, housing, building or industrial production end-use service.

- Minimize use of materials from a life cycle GHG intensity perspective
- Component recycling
- Non-destructive reuse of components
- Lengthen the functional life of a structure through adaption
- Lengthen service life



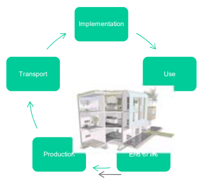
Life Cycle Assessment (LCA)

- LCAs assess the environmental aspects and potential impacts associated with a product process or service.
- Life cycle refers to the major activities in the course of the product's life
  - Raw Material Acquisition
  - Manufacture
  - Use
  - Maintenance
  - Final Disposal
    - Cradle to Grave
      - Landfill
    - Cradle to Cradle
      – Recycled or Upcycled

Two Dimensions in the Life Cycle Assessment: Environmental and Economics

1. Assess the environmental impacts of the products we manufacture and the systems / structures they are part of

2. And incorporate a cost factor to demonstrate their potential financial benefits on the long term.



Indicators	
Environmental indicators	**Cost**
Total Primary Energy	Life cycle cost
Fuel Energy	
Abiotic resource depletion	
Water consumption	
Greenhouse effect - IPCC 100 yrs	
Air acidification	
Waste production	
Recovered waste	
Air pollution	
water pollution	
Stratospheric ozon depletion	
Photochemical ozon formation	
Aquatic toxicity	
Human toxicity	
…	

Minimize/Reduce CO_2 in Cement Manufacture

Levers to reduce CO_2 emissions in Cement

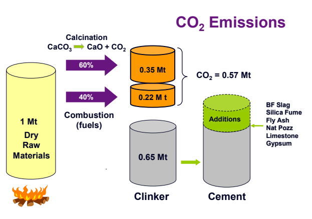
- Improve efficiency of assets
- Blended cements (increase C/K ratio)
- Alternate fuels (biomass)
- Alternate raw materials (e.g., steel slag)
- Reduce clinker production
- Clinker reactivity (to allow more SCMs)

Blended cements are a lever to reduce CO_2

Use of SCMs to Reduce CO_2

The CO_2 generated in the production of portland cement clinker can be minimized by incorporating SCMs

- As raw material substitute for limestone
- As a direct substitute for portland cement in concrete



CO_2 Reduction

Every ton of limestone replaced in the raw mix by SCMs reduces $C0_2$ by approximately 0.53 t per t of clinker

Every ton of clinker replaced by SCMs reduces CO_2 by approximately 0.88 t

Alternative Cements, Pozzolans, and Other Materials

Non-portland binders

- LC3
- Calcium Aluminate Cement
- Alkali Activated Slag and Fly Ash
- Calcium Sulfoaluminate Cement
- Recycled Glass-Based Cement
- Hydraulic Fly Ash Cement

Other Pozzolans

- Metakaolin, expanded shale, expanded slate, expanded clay, pumice, rice husk ash, volcanic ashes, and materials such as diatomaceous earth

Other Materials

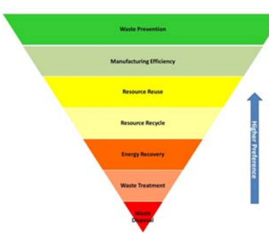
- Wood ash, various types of nonferrous slags, glass powder

Enhanced Proportioning is Key

- Binders
- Aggregate
  - Fine and Coarse
- Admixtures
- Water

Short Term CO_2 Reduction Strategy!

Hierarchy of Waste Management



Waste Management

1.43 billion US tons (1.3 metric tons) of construction and demolition waste

Sustainable Management

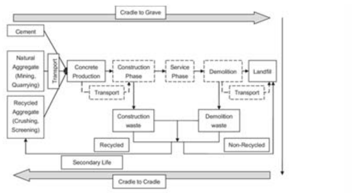
Elkington, 1997; Vásquez, 2013; Hultman and Corvellec, 2012; Perket, 2010

Recycling, Upcycling, and Downcycling

Recycling = the material is used for the same function again e.g., steel

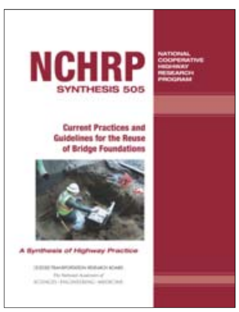
Upcycling = enhancement of value or utility through non-destructive recycling with some processing e.g., Fly Ash

Downcycling = the recycled material is only usable for other product applications, mostly substitution of other raw materials, e.g., recycled concrete aggregate as roadbase



Component Harvesting and Reuse

- In situ Reuse of Concrete Components
- Reuse of Concrete Components at an alternative site



Component Harvesting and Reuse




Spatial Reciprocal Frames

Subtle Frame Building

Modular Precast Structures

Modular systems

- Increase flexibility and exchangeability of spaces
- Improve the longevity of the structure
- Cost effective
- Reduces construction time
- Minimizes disruption in congested areas
- Reduces energy consumption

Ulrich and Eppinger, 1995; Altomonte and Luther, 2006; Lawson, 2008

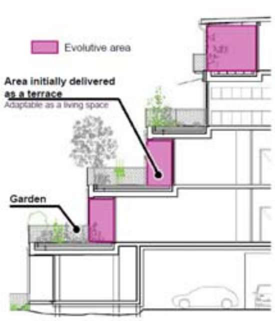
Building Adaptation

- Extending the life cycle of existing building stock
  - Conserves resources,
  - Retains cultural resources,
  - Reduces waste and the environmental impacts of creating and transporting new building materials
- Structural adaption requires a 'balance between durability and flexibility' from its original design.

Wosk Centre for Dialogue:
Vancouver heritage bank building
converted to conference centre

Keymer, 2000

Adaptable Housing - Les Hauts Plateaux



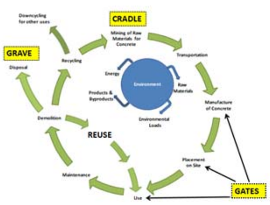
Beglés, France

Lafarge, 2015

Durability

- Durability refers to components and whole to perform functions in its service environment over planned period (of time) without cost of maintenance.
- Durable materials remain useful for longer periods of time, reducing:
  - Environmental impacts of component/wholesale replacement (waste, manufacturing, deconstruction debris)
- The increase in service life of the infrastructure is a very efficient way to increase the eco-efficiency of the economy. (Division of the total environmental load cradle-to-grave basis by its service life.)

Durability = Sustainability = Resilience

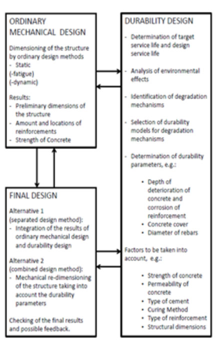


Enhancing long-term durability

- Significantly reduces the impact of operational embodied energy (non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems) during the structure's life span.
- Operational energy is heavily influenced by the durability and maintenance of construction materials, systems and components installed in the structure, and the life span of the structure.

Strategies for Implementation

- Maximized Service Life
- Durability and Robustness
  - Mechanical and Environmental Loading
  - Anticipated Deterioration Mechanisms
  - Durability Risks
    - Present
    - Future
- Hazard Risks
  - Natural and Manmade



Sarja, 2000

Service Life

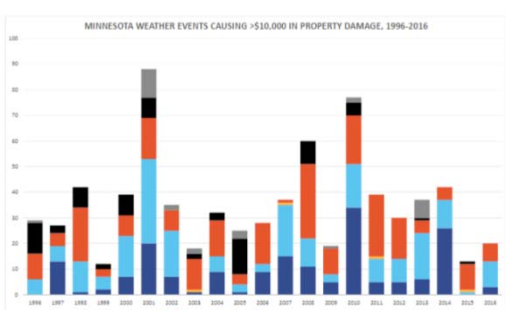
- The service life and utility of concrete is strongly dependent upon its transport properties (i.e. permeability, sorptivity and chloride permeability).
- The ingress of potentially deleterious materials such as chlorides, sulfates and water by diffusion and capillary transport can lead to the corrosion of steel reinforcement or a reduction of strength due to cracking by frost or sulfate attack.

Reassessment of Climatic Conditions

- **Regional vs. Global**
  - Microclimates
- **Atmospheric Cycles**
  - Natural cycles – millennial, century, decadal, interannual,
    - e.g. El Nino,
- **Slow Onset Events (SOEs) vs. Extreme Events**

Warsaw International Mechanism for Loss and Damage, 2013

Minnesota Weather Events

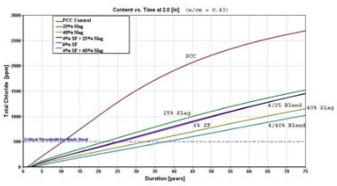


Resilient Adaptation of Sustainable Buildings, Center for Sustainable Building Research, 2018

Minnesota – Future Climatic Conditions

Name	Radiative Forcing (W/m^2)	CO_2e (ppm)	Temperature Anomaly (°C / °F)	Pathway
RCP8.5	8.5 in 2100	1370	4.9/8.8	Rising
RCP6.0	6.0 post 2100	850	3.0/5.4	Stabilization without overshoot
RCP4.5	4.5 post 2100	650	2.4/4.3	Stabilization without overshoot
RCP2.6 (RCP3PD)	3.0 beore 2100, declining to 2.6 by 2100	490	1.5/2.7	Peak and decline

Representative Concentration Pathways for Use in Climate Predictions

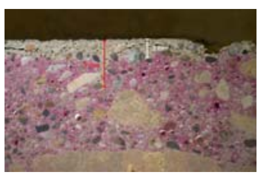


Deterioration Modeling

- **Minor**
  - Seismic
  - Fire
- **Major**
  - Corrosion
  - Stormwater management
    - Water Quality
    - Scour
    - Erosion
  - Snow and Wind Loads
  - Tornado

Implications of Climate Change on Concrete

- **Carbonation**
  - CO_2 levels,
  - Relative humidity
- **Corrosion**
  - CO_2 levels,
  - Temperature,
  - Relative humidity
  - Sea water level,
  - Nutrient concentration,
  - Ocean acidification,
  - Time of saturation,
  - Airborne salinity, and
  - Airborne pollutants.



Other Climate Impacts

- **Atmospheric Pollutants**
  - Dry and Wet Deposition
    - NO_x and SO2
- **Extreme Loads and Impacts from Extreme Hazards**
  - Tornadoes
  - Hurricanes and Tsunamis
  - Snow and Wind Loads
  - Earthquake
  - Rain
  - Fire
  - Blast Resistance

Implications of Climate Change on Structures

HAZARD	ROUTINE	DESIGN	EXTREME
GROUND SNOW	50 YEAR MRI OR 64% IN 50 YEARS	300 TO 500 YEAR MRI[1] OR 15 TO 10% IN 50 YEARS	TBD[4]
RAIN	LOCALLY DETERMINED[2]	LOCALLY DETERMINED[2]	LOCALLY DETERMINED[2]
WIND- NON-HURRICANE	50 TO 100 YEAR MRI OR 64 TO 39% IN 50 YEARS	700 YEAR MRI OR 7% IN 50 YEAR	1,700 YEAR MRI[3] OR 3% IN 50 YEARS
WIND - HURRICANE	50 TO 100 YEAR MRI OR 64 TO 39% IN 50 YEARS	700 YEAR MRI OR 7% IN 50 YEAR	1,700 YEAR MRI[3] OR 3% IN 50 YEARS
WIND - TORNADO	LOCALLY DETERMINED[3]	LOCALLY DETERMINED[3]	LOCALLY DETERMINED[3]
EARTHQUAKE	50 YEAR MRI OR 64% IN 50 YEARS	50 YEAR MRI OR 10% IN 50 YEARS	2,500 YEAR MRI OR 2% IN 50 YEARS
TSUNAMI	LOCALLY DETERMINED[3]	LOCALLY DETERMINED[3]	LOCALLY DETERMINED[3]
FLOOD	LOCALLY DETERMINED	100 TO 500 YEARS MRI OR 39 TO 10% IN 50 YEARS	LOCALLY DETERMINED
FIRE- WILDFIRE	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]
FIRE- URBAN/MANMADE	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]
BLAST/ TERRORISM	LOCALLY DETERMINED[5]	LOCALLY DETERMINED[5]	LOCALLY DETERMINED[5]

[1]For the Northeast, 1.6 (the Load and Resistance Factor Design (LRFD) factor on snow load) times the 50-year ground snow load is equivalent to the 300 to 500 year snow load.

[2] Rain is designed by rainfall intensity of inches per hour or mm/h, as specified by the local code.

[3]Tornado and tsunami loads are not addressed in ASCE 7-10. Tornadoes are presently classified by the EF scale. See FEMA 361 [2015] for tornado EF-scale wind speeds.

[4]Hazards to be determined in conjunction with design professionals based on deterministic scenarios.

[5]Hazards to be determined based on deterministic scanarios.

Design for Extreme Loadings

High-Performance Building Codes

HAZARD	ROUTINE	DESIGN	EXTREME
GROUND SNOW	50 YEAR MRI OR 64% IN 50 YEARS	300 TO 500 YEAR MRI[1] OR 15 TO 10% IN 50 YEARS	TBD[4]
RAIN	LOCALLY DETERMINED[2]	LOCALLY DETERMINED[2]	LOCALLY DETERMINED[2]
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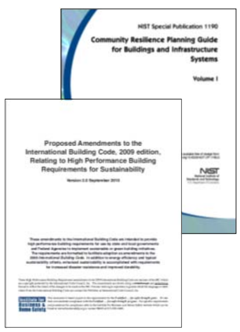
FIRE- URBAN/MANMADE	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]
BLAST/ TERRORISM	LOCALLY DETERMINED[5]	LOCALLY DETERMINED[5]	LOCALLY DETERMINED[5]

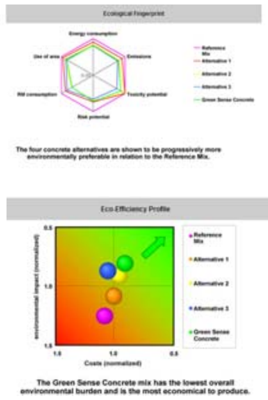


Influencing the Building Code

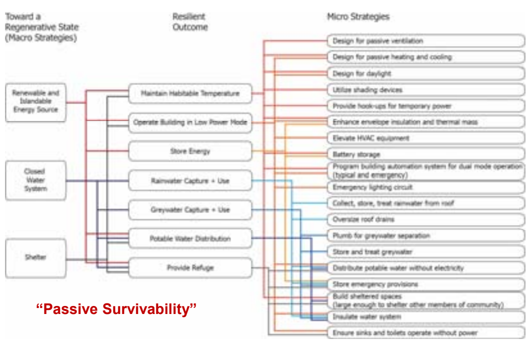
- **Influencing Infrastructure Management Policies**

Eco-Efficiency Calculators

Identification of Products and Processes that consume less energy and generate less waste than alternatives while maintaining or improving the products' commercial value.



Regenerative & Resilient Goals



Resilient Adaptation of Sustainable Buildings, Center for Sustainable Building Research, 2018

Industry Collaboration

- Internal Collaboration
  - World-wide collaboration between cement and concrete industries on sustainability & resilience
- External Collaboration
  - US Resiliency Council
  - FLASH – Federal Alliance for Safe Homes
  - CARRI – Community and Regional Resilience Institute
  - ReScU - Resilient Scoring Utility for Homes by Homeland Security
  - IBHS – Institute for Business and Home Safety
  - NIBS – National Institute of Building Sciences
  - University of Minnesota

IBHS

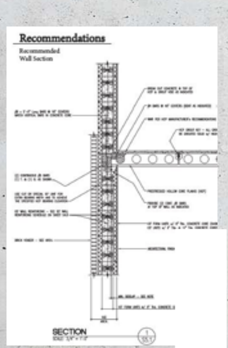
Insurance Institute for Business and Home Safety (IBHS) criteria that greatly increase a new commercial building's durability and resilience to natural and manmade hazards


TABLE OF CONTENTS

IBHS FORTIFIED for Safer Business Designation (3 points)

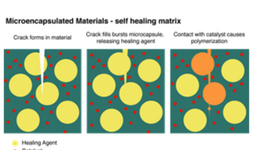
Achieve the Insurance Institute for Business and Home Safety's (IBHS) FORTIFIED for Safer Business (FFSB) designation. To qualify for this credit option the building must meet all design, construction and inspection criteria such that the building receives the IBHS FORTIFIED for Safer Business designation.

NRMCA CONCRETE DESIGN CENTER



Structural Design
Cost Estimates
Energy Analysis
LEED Optimization
Whole Building LCA

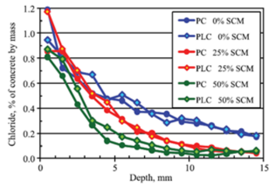
Design and Adoption of….



- Innovative Materials
- Construction Practices
- Maintenance Solutions

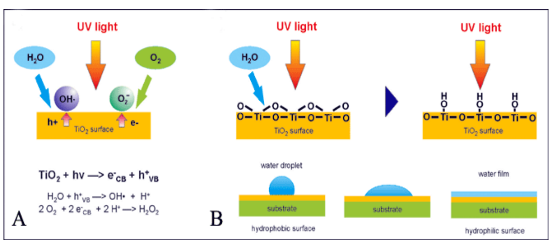
Innovative Strategies

- Alternative or Blended Binders
  - Alternatives to Portland Cement, Ternary and Quaternary Blends
- Admixture Technologies
  - Shrinkage-Reducing Admixtures
  - Corrosion Inhibitors
  - Others
- Recycled Materials
  - Aggregates and others
- Curing Mechanisms
- Simulation Technologies
  - STADIUM, Life 365



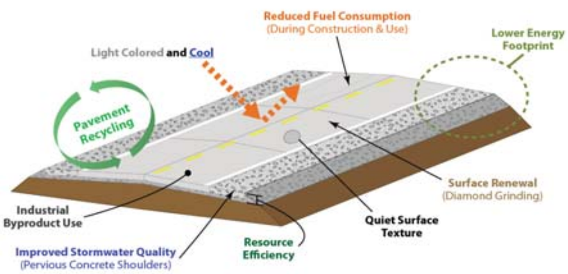
Chloride Profiles in Concrete Cores Extracted from Pavement Slabs

De-Polluting Cement and Concretes with TiO2



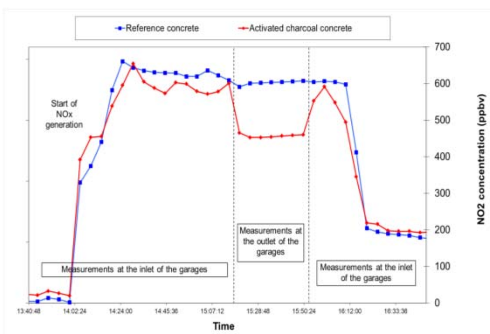
Innovation – Jubilee Church, Rome

Pavements



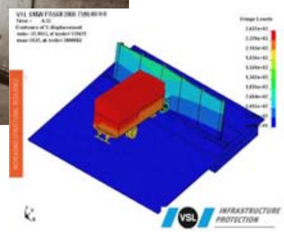
These are sustainable attributes and offer some solutions to lowering the impacts on the environment….. Is it enough?

Depolluting Concrete with Activated Charcoal



Innovation – UHPC and UHPFRC

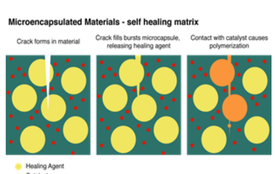
Innovation – Blast Resistance

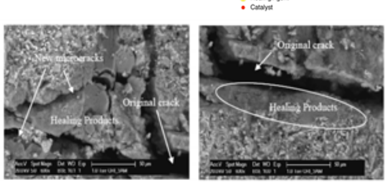


Self-Healing Concretes

Multiple Technologies

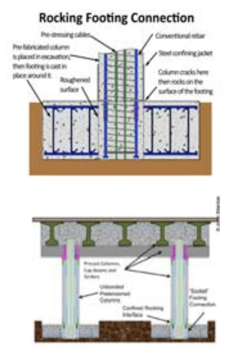
- Polymeric
- Biological





Innovative Design Solutions

- **Substructures**
  - **Foundations, Ground Floors**
    - **Energy Pile, Flowable Fill, Jet Grout Foundations, Large slabs, Rocking Footing Connection, Slurry Infiltrated Mat Concrete**
- **Superstructure**
  - **Frame, Upper floors, Roof, Non-structural walls, Columns**
    - **Semi-precast double wall, Hollow Column with Air Circulation, Double skin walls, Cement earth block, Floors with void formers, Thermoactive Hollowcore Precast Slabs, Prestressed Open Space Truss, etc.**
- **Internal Finishes**
  - **Floor Finishes**
    - **Underfloor Heating with Self-leveling Screed, Colored Concrete**

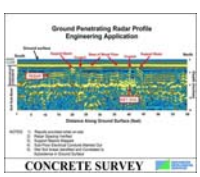


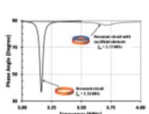
Construction Practices

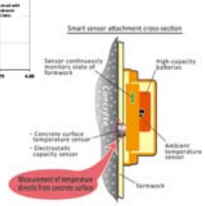
- **3-D Printing**
- **HPC Precast frames**
  - **Adaptable**
- **Precast pavements**
- **Precast bridges**

Maintenance Solutions

- **High-speed and High-resolution, nondestructive technologies**
  - **BIM**
  - **Inspection**
  - **Evaluation**
  - **Performance Monitoring**
    - **RFID**
- **Maintenance Programs**
  - **Periodic and continuous performance**





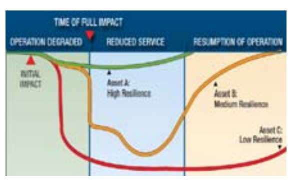


Closing Comments

Resilience is a "Subset" of Sustainability

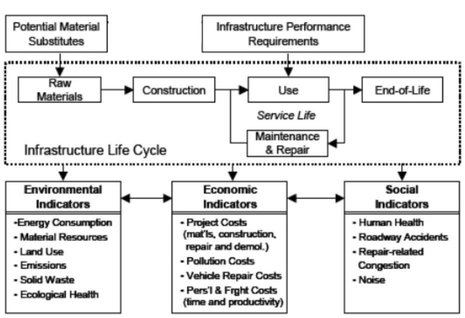
Adoption

- High-performance codes
- Material Efficiency
- Innovative practices



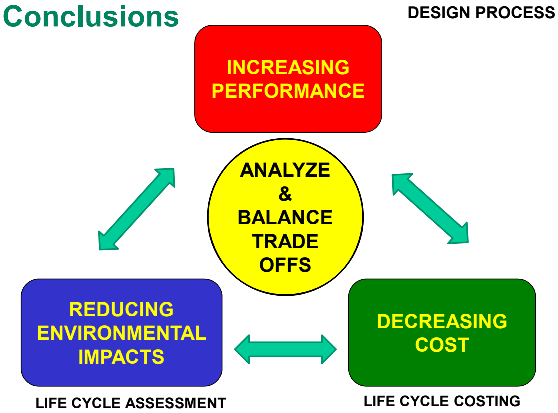
NRMCA, InFocus, Spring 2012; M. Kennett, Resilient Buildings Workshop, November 2012.

Infrastructure Life Cycle



* University of Michigan. 2006. Sustainable Concrete and Infrastructure Systems.

Conclusions

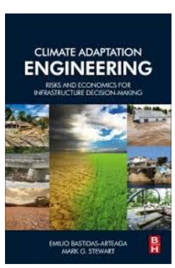


Conclusions

- It is imperative to include durability, robustness and adaptability into the original design of structures to accommodate resilience to natural and manmade disasters.
- Sustainable and Resilient considerations should be intertwined in design of structures for the future.
- Designing functional resilience into structural design will support the resilience of the community.
- Design choices must consider present climatic conditions but also future climatic conditions while being practical and easily employed in the structures.

Conclusions

- Sustainability and Resiliency are now being recognized as a vital and central core to urban development.
- Concrete is a construction material that plays an important positive role in minimizing the impacts of our built civilization by providing resilient social, environmental and economic benefits.



Bastidas-Artega & Stewart, 2019


Questions ?
BETON