FRIC FIRE RESEARCH & INNOVATION CENTRE

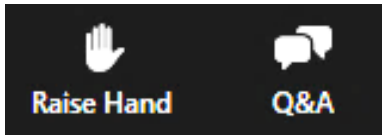
@FRICfirecentre

Welcome to this FRIC webinar!

2021-09-27
The webinar will start at 11 am

Please notice that the webinar will be recorded

- During the webinar, your microphone and camera will be turned off by default, by the host.
- Please use the Q&A to ask questions or raise your hand if you wish to speak:



There will be several more FRIC webinars this fall, more info will come on fric.no and our social media

FIRE SAFETY CHALLENGES OF ‘GREEN’ BUILDINGS AND ATTRIBUTES

Margaret McNamee, Fire Safety Engineering, Lund University
Brian Meacham, Meacham Associates

Background

- Focus on 'green' or sustainable buildings for three decades.
- Not much focus on fire performance of 'green' buildings.
- Review in 2012 sponsored by the FPRF. Update in 2020.
- What has been addressed, what is new, where are gaps, what can be done?

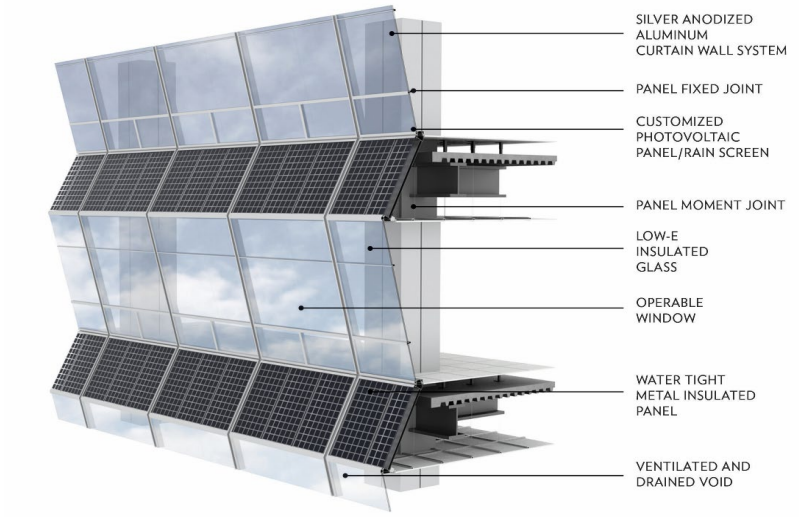
Figure 3.9 Aftermath of Delanco, NJ, Warehouse Fire (Courtesy of New Jersey State Fire Marshal Office)

Figure 3.10 Fire in Timber Frame Apartment Building Under Construction (Source: Captain John Bonadio, Waltham Fire Department, as published at https://www.enr.com/articles/42484-what-local-officials-want-to-do-about-wood-frame-building-fires-in-massachusetts), Courtesy of Waltham, Massachusetts Fire Department)

Overview of Topics for Today

- What is "green"?
- What the fire statistics tell us
- What the media tells us
- Recent technological developments
- Updated risk and hazard matrices
- SAFR-Buildings

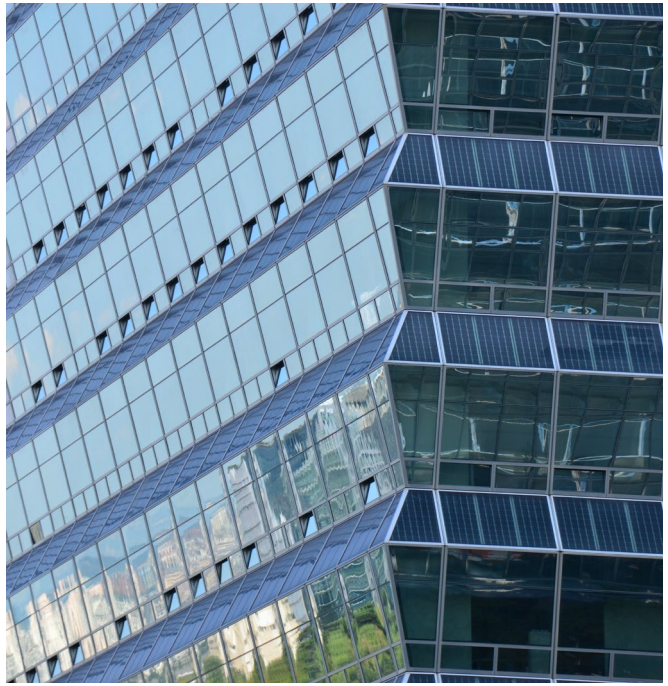
Fire in Timber Frame Apartment Building Under Construction (Source: Captain John Bonadio, Waltham Fire Department, as published at https://www.enr.com/articles/42484-what-local-officials-want-to-do-about-wood-frame-building-fires-in-massachusetts (last accessed September 2020), Courtesy of Waltham, Massachusetts Fire Department)



FKI Tower Exterior Wall Diagram (©Adrian Smith + Gordon Gill Architecture, reprinted with permission)

What is "green"?

- "A 'green' building is a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment. 'Green' buildings preserve precious natural resources and improve our quality of life." (WGBC)



FKI Tower Exterior Façade Photo (©Adrian Smith + Gordon Gill Architecture, reprinted with permission)

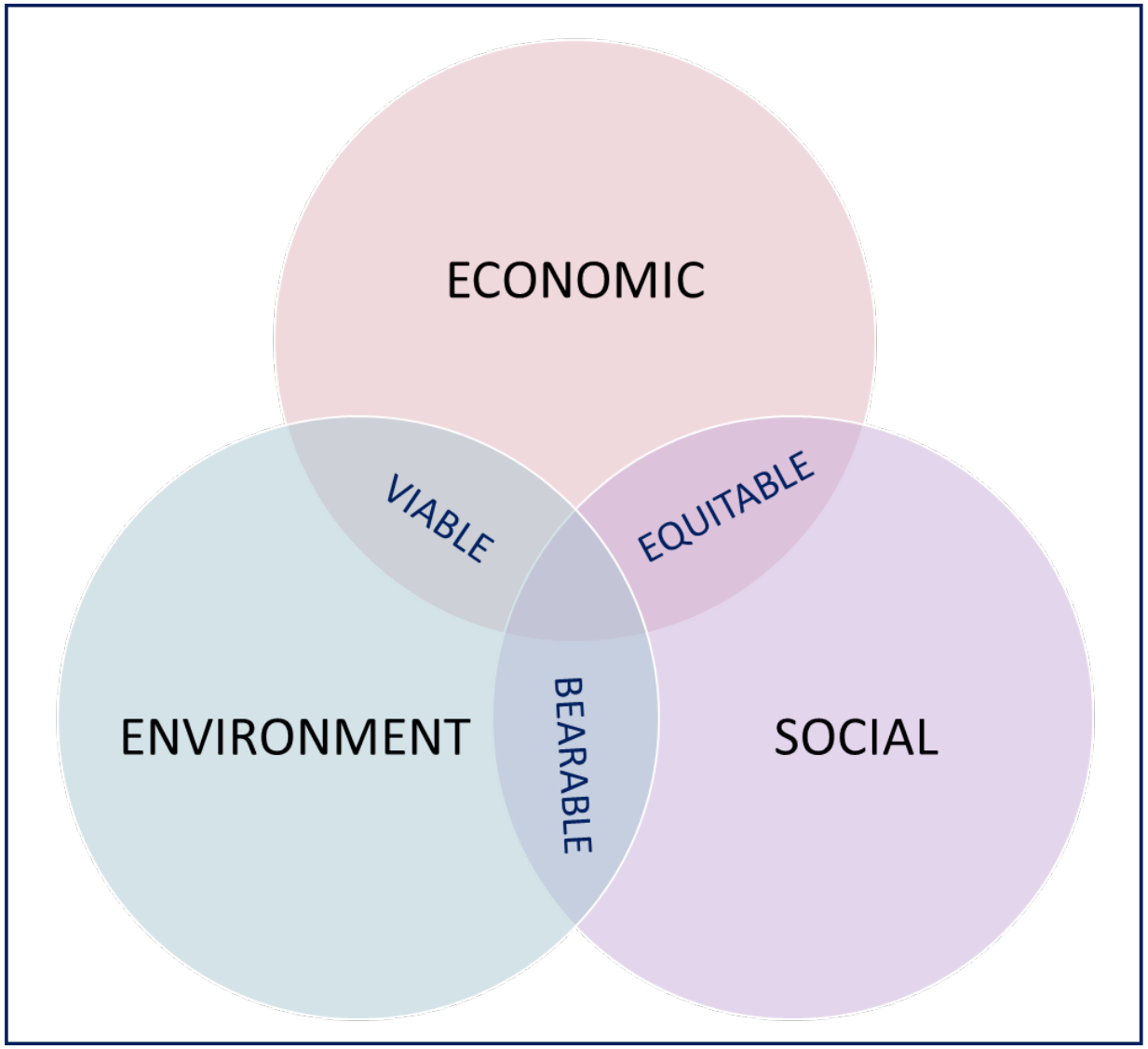
What do we mean by sustainability?

A sustainable society meets our present needs without compromising the ability of future generations to meet their needs

(Brundtland Report, 1987)

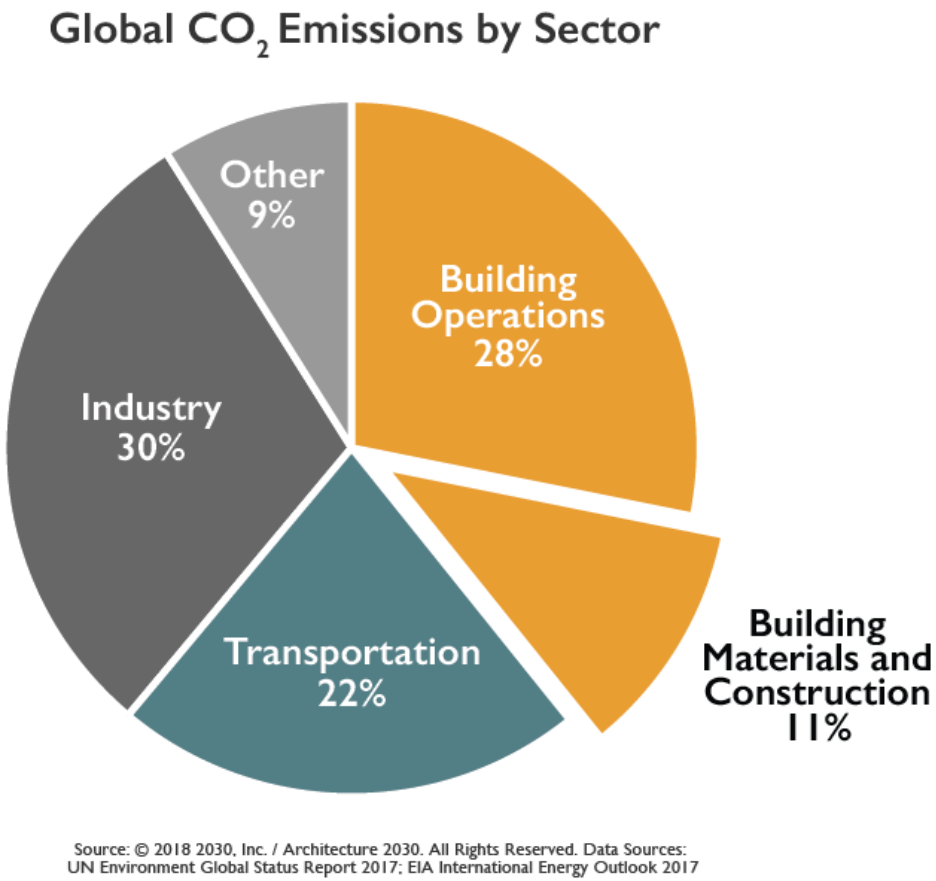
Economic, social and environmental issues tend to be dealt with separately. They are different dimensions of sustainability and need to be considered together.

(Agenda 21, 1992)



"Green" / Sustainability Strategies for Buildings

- Reduce energy from fossil fuel sources
- Reduce construction materials
- Reduce transportation



https://architecture2030.org/new-buildings-embodied/

Reducing Fossil Fuel Energy Requirements

- Reduced electrical lighting loads
- Reduced mechanical heating and cooling equipment
- Alternative / renewable energy
- Increase thermal insulation
- Green & blue roofs

"Green" Building in Singapore, Courtesy Brian Meacham.

"Constellation Energy Solar at Patriot Place 4-19-10.2" by Constellation Energy is licensed with CC BY-ND 2.0.

Reducing Materials Impact on Environment

- Reduce construction material (lower embodied energy)
- Increase use of more sustainable materials
- Increase use of recycled materials
- Reduce construction waste

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What the Fire Statistics Tell Us

- Finding 'clear' data on fires involving 'green' buildings and attributes is difficult – *because buildings and attributes are not defined this way*

Table 3.1 NFIRS Data Collection based on Raw Data and National Estimates (2007-2011) (You et al., 2014)

Fire Suppression Factors Code	Factors Related to Green Building Features	Incidents having this Factor: Raw Data	Incidents having this factor: National Estimates	Total Incidents
182	Composite plywood I-beam construction	19	100	42
183	Composite roof/floor sheathing construction	32	149	N/A
185	Wood truss construction	267	1333	N/A
186	Metal truss construction	3	20	N/A

What the Fire Statistics Tell Us

- Finding 'clear' data on fires involving 'green' buildings and attributes is difficult – *because buildings and attributes are not defined this way*

Table 3.5 NFIRS Raw Data - Suppression Factor 115 – Solar Panels, 2013-2018 (Meacham & McNamee, 2020)

Alarm Year	Number of Fires	PCT	Civilian Fatalities	PCT	Civilian Injuries	PCT	Dollar Loss	PCT
2013	8	11.0%	0	0.0%	0	0.0%	$1,973,000	20.0%
2014	8	11.0%	0	0.0%	0	0.0%	$323,850	3.3%
2015	9	12.3%	0	0.0%	0	0.0%	$1,566,500	15.9%
2016	19	26.0%	0	0.0%	1	100.0%	$1,818,600	18.4%
2017	17	23.3%	0	0.0%	0	0.0%	$2,439,800	24.7%
2018	12	16.4%	0	0.0%	0	0.0%	$1,760,000	17.8%
TOTALS	**73**	**100.0%**	**0**	**100.0%**	**1**	**100.0%**	**$9,881,750**	**100.0%**

What the Fire Statistics Tell Us

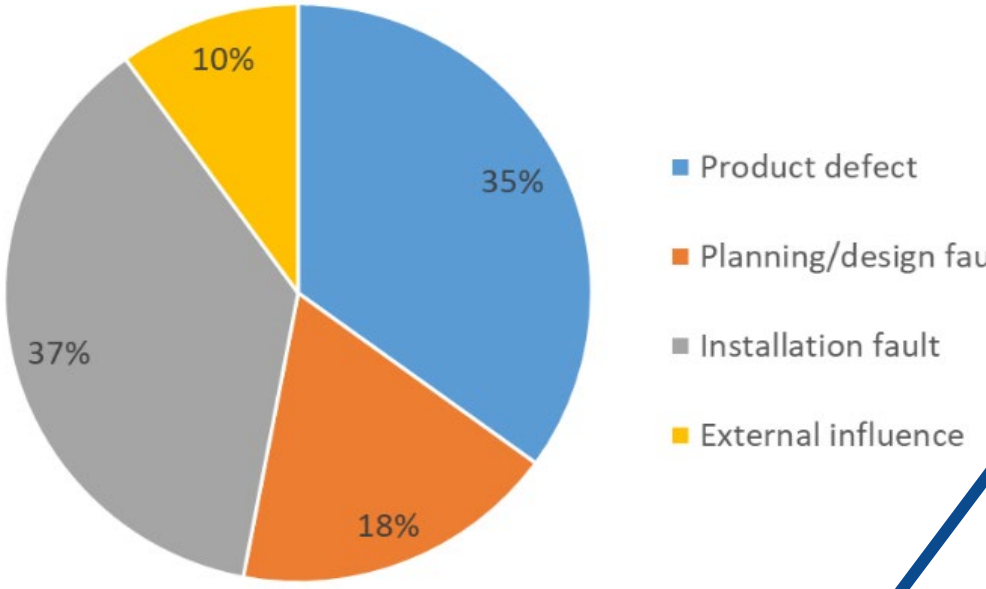
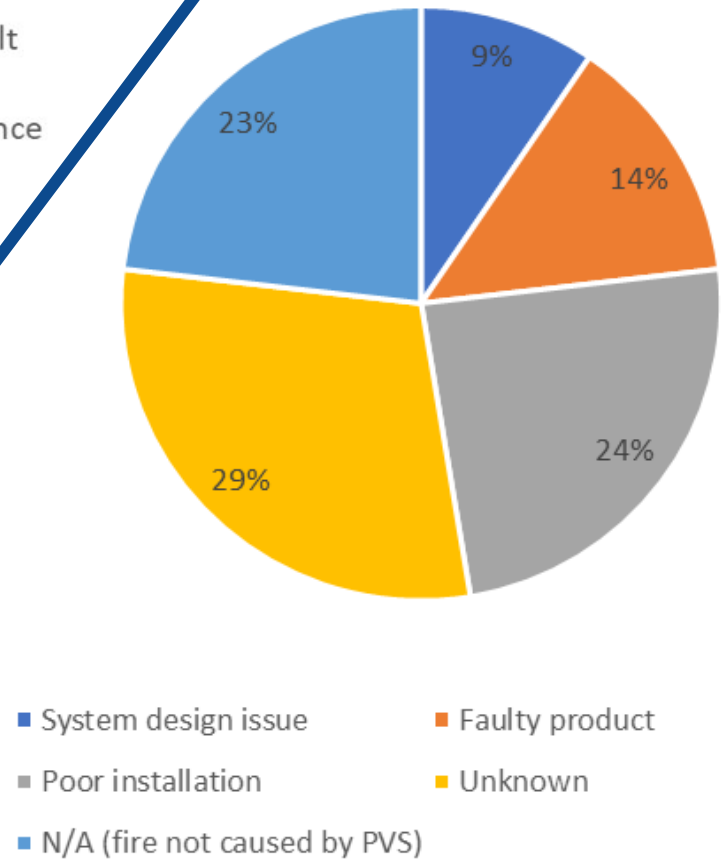


Figure 3.2 Distribution of Identified Causes of PVS Fire - Germany (Laukamp et al., 2013)



General Interpretation of Root Cause of Fires involving PVS - UK (Coonick and Bregulla, 2018)

What the Fire Statistics Tell Us

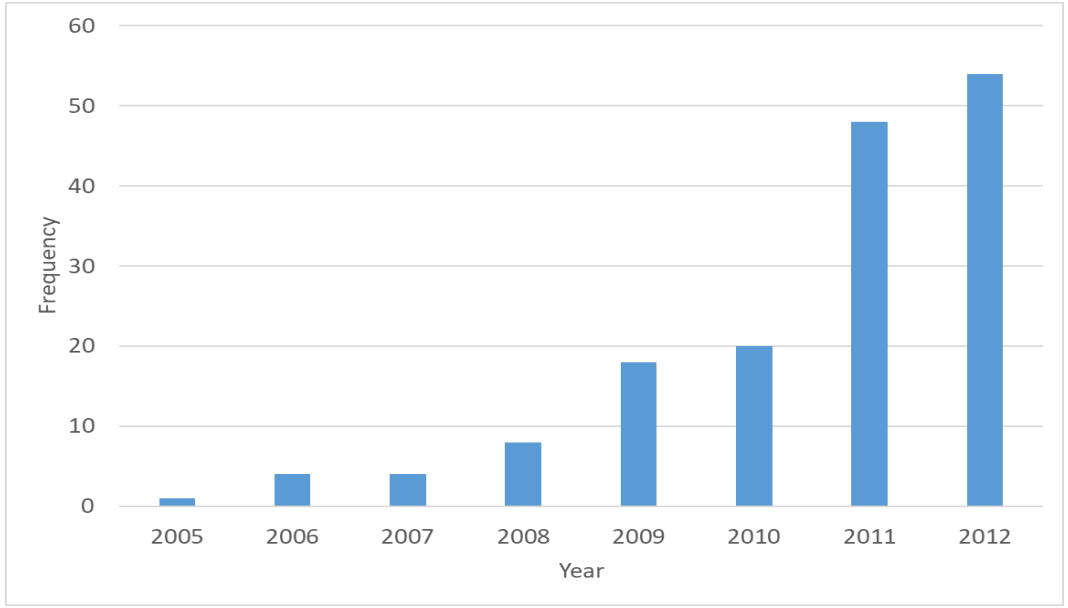


Figure 3.4 Number of PV Incidents Per Year – Germany (Laukamp et al., 2013)

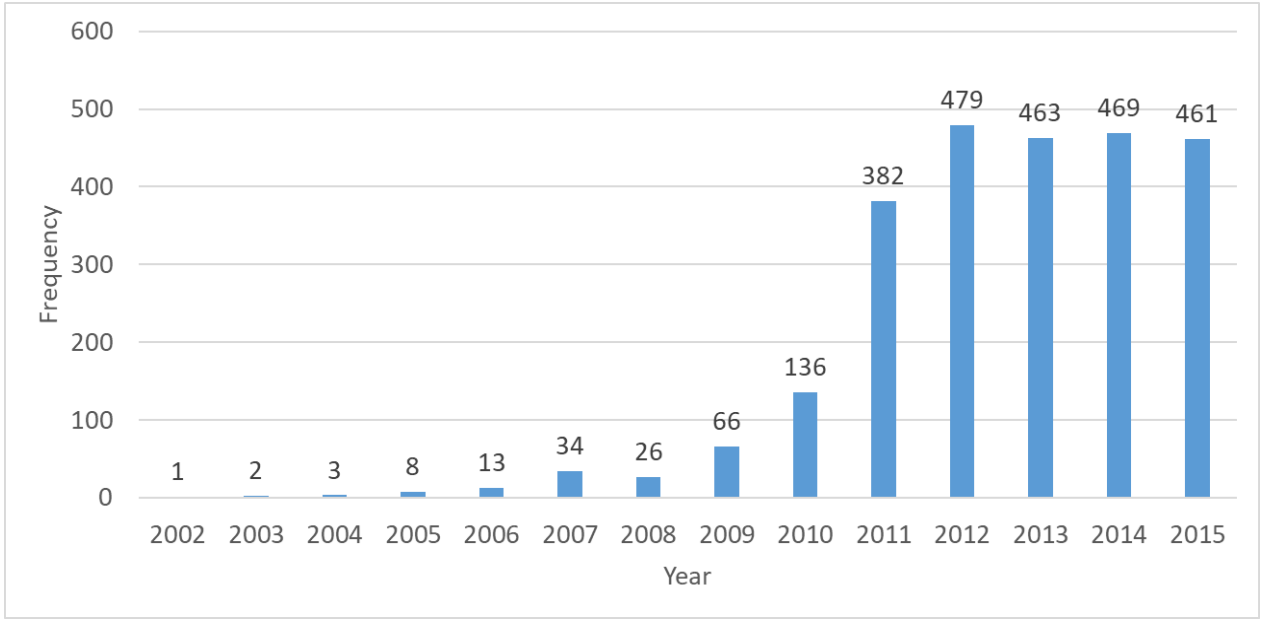


Figure 3.5 Fire Incidents in PV Systems in Italy by Year, 2002-2015 (Bonomo et al., 2017)

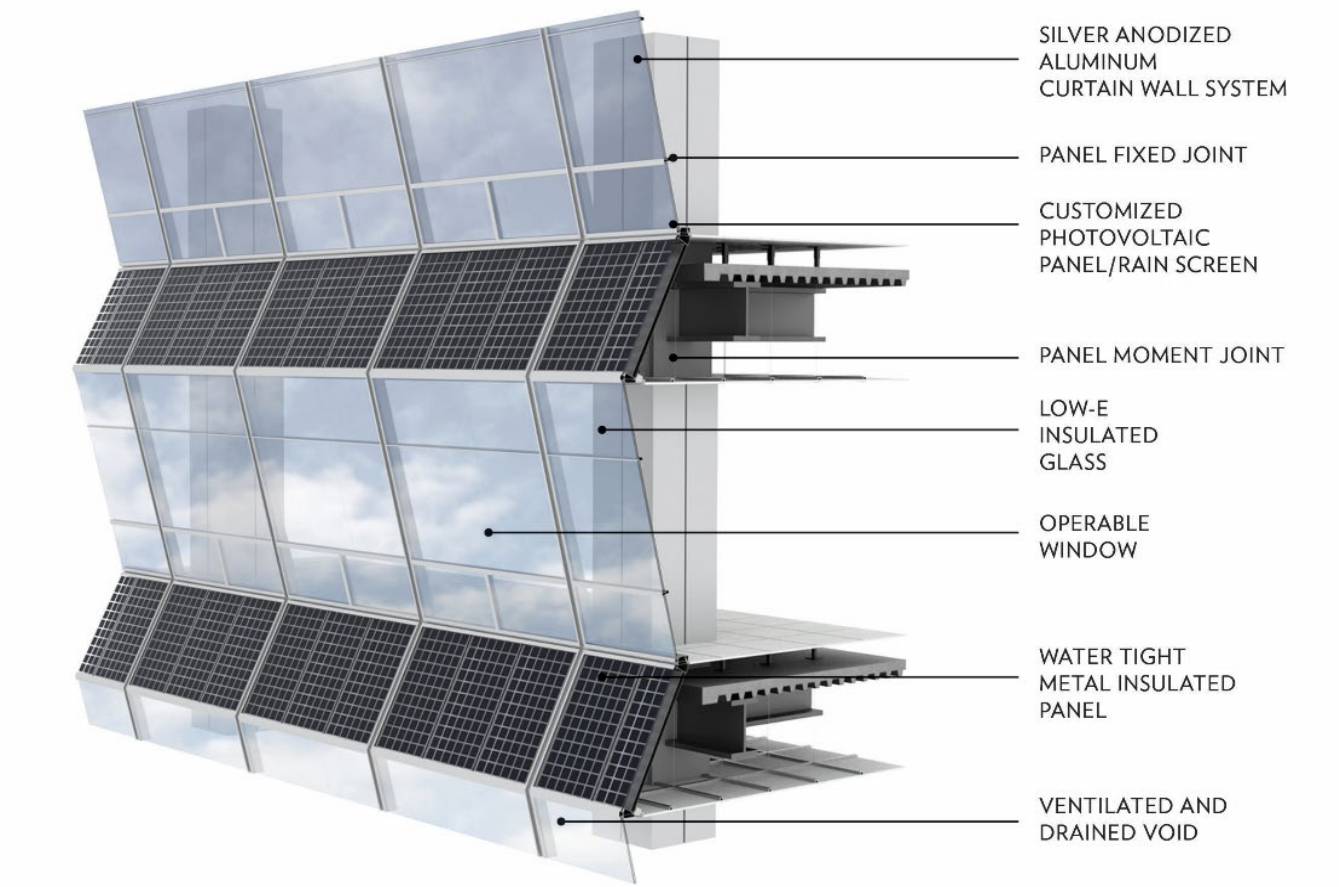
What the Media Tells Us

Figure 3.9 Aftermath of Delanco, NJ, Warehouse Fire (Courtesy of New Jersey State Fire Marshal Office)

Figure 3.10 Fire in Timber Frame Apartment Building Under Construction (Source: Captain John Bonadio, Waltham Fire Department, as published at https://www.enr.com/articles/42484-what-local-officials-want-to-do-about-wood-frame-building-fires-in-massachusetts), Courtesy of Waltham, Massachusetts Fire Department)

Recent Technological Developments & Trends – Systems

- Building-Integrated Carbon Capture
- Building-Integrated Photovoltaics



FKI Tower Exterior Wall Diagram (©Adrian Smith + Gordon Gill Architecture, reprinted with permission)

Recent Technological Developments & Trends – Materials

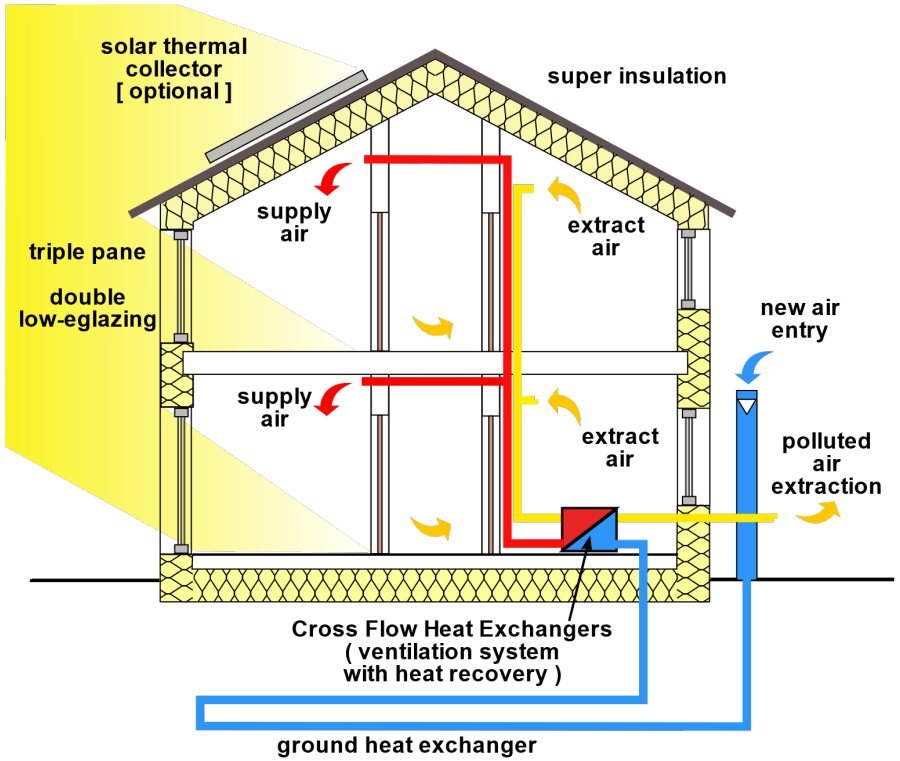
- Low Carbon Emission Concrete
- Hempcrete
- Stabilized Aluminum Foam
- Inflated Steel Structures
- PET for Buildings
- Novel Biological Material
- Phase Changing Materials
- *Mass Timber*
- *Lightweight Engineered Lumber*

By Øyvind Holmstad - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=79435356

Recent Technological Developments & Trends – Design & Construction

- BIM and Digitalization
- Additive Manufacturing/3D Printing
- Interactive Printed Graphene
- *Passiv Haus*
- *Modular Construction*

Modular Construction in Singapore, Courtesy Brian Meacham.



By Passivhaus_section_en.jpg: Passivhaus Institutderivative work: Michka B (talk) - Passivhaus_section_en.jpg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=9586761

Recent Technological Developments & Trends – Site

"Avista's new energy storage system" by WaStateGov, https://search.creativecommons.org/photos/bccf36ae-0693-497b-9691-eb1caee5ae42, is licensed with CC BY-ND 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-nd/2.0/

Exemplar EV (Chevrolet Bolt) (Courtesy Brian Meacham)

Green Buildings & Attributes

- More that 100 materials, systems and features grouped into 9 categories
  - Structural Materials and Systems
  - Exterior Materials and Systems
  - Façade Features
  - Interior Materials and Finishes
  - Interior Space
  - Building Systems
  - Alternative Energy Systems
  - Site

Green Buildings & Attributes

Material / System / Feature	Material / System / Feature	Material / System / Feature
Structural Materials and Systems	**Exterior Materials and Systems**	**Alternative Energy Systems**
- Lightweight engineered lumber	- Structural integrated panel (SIP)	- PV roof panels
- Lightweight concrete	- Exterior insulation & finish (EFIS)	- Oil-filled PV panels
- FRP elements	- Rigid foam insulation	- Wind turbines
- Plastic lumber	- Spray-applied foam insulation	- Hydrogen fuel cells
- Bio-polymer lumber	- Foil insulation systems	*- Battery / energy storage systems*
- Bamboo	- High-performance glazing	- Cogeneration systems
- Phase-change materials	- Low-emissivity & reflective coating	- Wood pellet systems
- Nano materials	- Double-skin façade	*- Building integrated photovoltaics*
- Vegetative roof systems	- Bamboo, other cellulosic	*- Solar radiance concentration*
- Extended solar roof panels	- Bio-polymers, FRPs	**Façade Features**
- Mass timber (e.g., CLT)	- Vegetative roof systems	- Area of glazing
- Additive manufacturing / 3-D printing	- PVC rainwater catchment	- Area of combustible material
- Inflated steel structure	- Exterior cable / cable trays	- Exterior solar shades & awnings
- Hempcrete	- Exterior solar shades / awning	- Exterior vegetative covering
- Ultra-High Performance Concrete	- Exterior vegetative covering	*- Out of plane geometries*
- Carbon fiber composites	*- Alusion Panels*	*- Solar radiance concentration*
- Modular construction	*- PET for façade system*	**Site**
Interior Materials and Finishes	*- Interactive printed graphene*	- Permeable concrete systems
- FRP walls / finishes	*- Novel biological materials*	- Permeable asphalt paving / pavers
- Bio-polymer wall / finishes	*- Building integrated carbon capture*	- Extent (area) of lawn
- Bamboo walls / finishes	*- Organic insulation*	- Water catchment / features
- Wood panel walls / finishes	*- Composite window framing material*	- Vegetation for shading
- Bio-filtration walls	*- Mass timber & timber façade systems*	- Building orientation
- Glass walls	*- Ultra-High Performance Concrete*	- Increased building density
- FRP flooring	*- Additive manufacturing / 3-D printing*	- Localized energy production
- Bio-polymer flooring	*- Hempcrete*	- Localized water treatment
- Bamboo flooring	**Building Systems**	- Localized waste treatment
- Interior vegetation	- Natural ventilation	- Reduced water supply
- Skylights	- High volume low speed fans	- Hydrogen infrastructure
- Increased acoustic insulation	- Refrigerant materials	- Community charging stations
- Reflecting panels / solar tubes	- Grey-water for suppression	*- EES fuel loads / hazards*
- Mass timber (e.g., CLT)	- Rain-water for suppression	*- EV fuel load / hazards / chargers*
Interior Space	- On-site water treatment	*- Propane vehicle hazards*
- Tighter construction	- On-site waste treatment	*- Fuel cell vehicle hazards*
- Higher insulation values	- On-site cogeneration	*- Bicycle storage impact exits*
- More enclosed spaces	- High reliance on natural lighting	*- Reduced FD apparatus access*
- More open space (horizontal)	*- Heat pumps*	*- Densification / fire spread*
- More open space (vertical)	*- Interior EV charger*	*- EV chargers on building exterior*

Green Buildings & Attributes

"New" Green Building Materials, Systems and Features Since 2012

- **Structural Materials and Systems**
  - *Mass timber (e.g., CLT)*
  - *Additive manufacturing / 3-D printing*
  - *Inflated steel structure*
  - *Hempcrete*
  - *Ultra-High Performance Concrete*
  - *Carbon fiber composites*
  - *Modular construction*
- **Exterior Materials and Systems**
  - *Alusion Panels*
  - *PET for façade system*
  - *Interactive printed graphene*
  - *Novel biological materials*
  - *Building integrated carbon capture*
  - *Organic insulation*
  - *Composite window framing material*
  - *Mass timber & timber façade systems*
  - *Ultra-High Performance Concrete*
  - *Additive manufacturing / 3-D printing*
  - *Hempcrete*
- **Interior Materials and Finish**
  - *Mass timber (e.g., CLT)*
- **Façade Attributes**
  - *Out of plane geometries*
  - *Solar radiance concentration*
- **Building Systems and Issues**
  - *Interior EV chargers*
  - *Heat pumps*
- **Alternative Energy Systems**
  - *Battery / energy storage systems*
  - *Building integrated photovoltaics*
  - *Solar radiance concentration*
- **Site Issues**
  - *EES fuel loads / hazards*
  - *EV fuel load / hazards / chargers*
  - *Propane vehicle hazards*
  - *Fuel cell vehicle hazards*
  - *Bicycle storage impact exits*
  - *Reduced firefighter apparatus access*
  - *Densification / fire spread*

Potential Risks and Fire Hazards

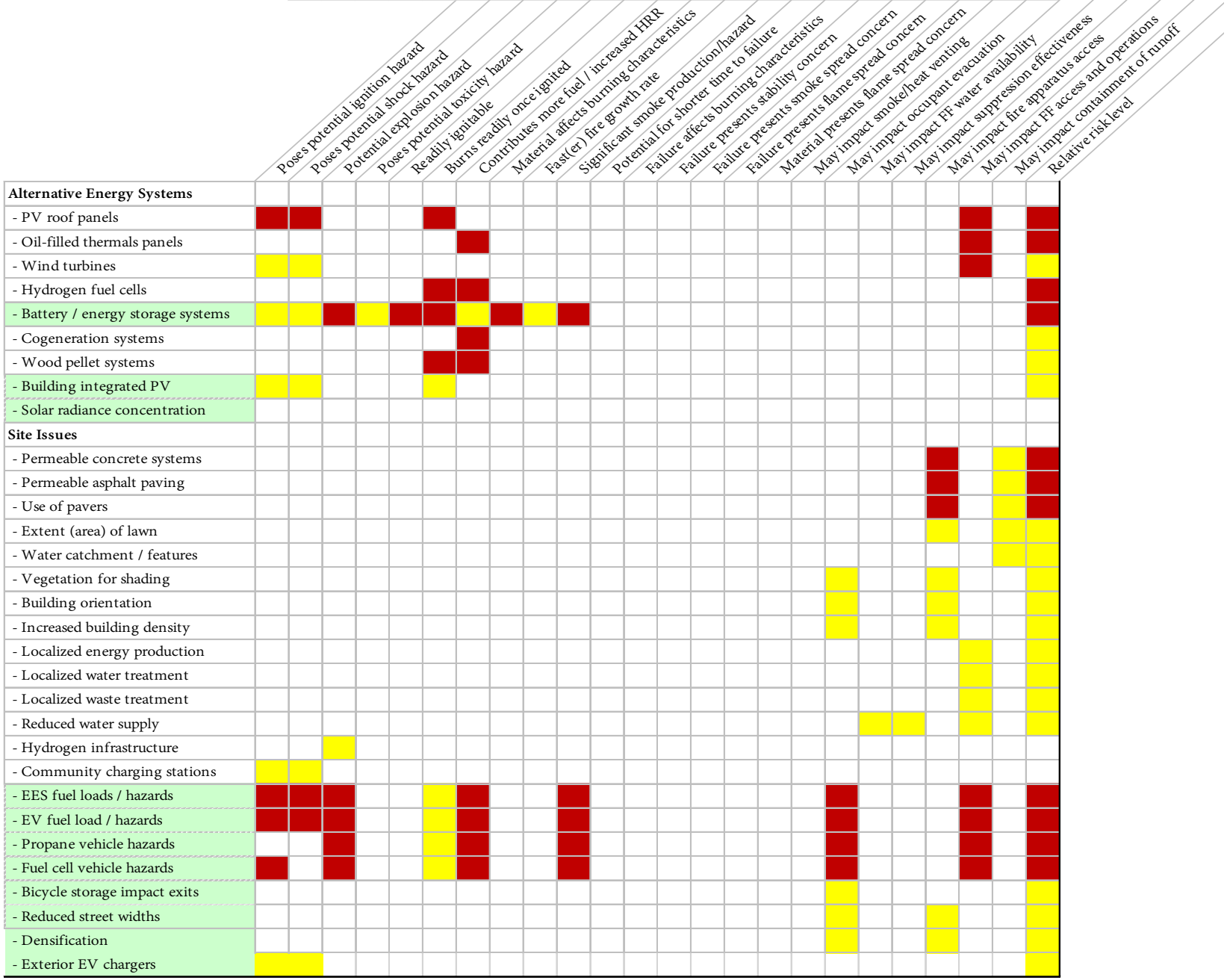
Potential Risks / Hazards

Poses potential ignition hazard
Poses potential shock hazard
Poses potential explosion hazard
Poses potential toxicity hazard
Readily ignitable
Burns readily once ignited
Contributes more fuel / increased heat release rate (HRR)
Material affects burning characteristics
Fast(er) fire growth rate
Significant smoke production/hazard
Potential for shorter time to failure
Failure affects burning characteristics
Failure presents smoke spread concern
Failure presents flame spread concern
Material presents flame spread concern
May impact smoke/heat venting
May impact occupant evacuation
May impact fire-fighter (FF) water availability
May impact suppression effectiveness
May impact fire apparatus access
May impact fire-fighter (FF) access and operations
May impact containment of runoff

Relative Fire Risk / Hazard Ratings

- The framing was an assessment of relative risk, for each 'element' and 'hazard' pair:
  - the relative risk of __, for the element __, if unmitigated, is low, moderate or high.
- Therefore, these rankings are applicable only for a specific element across the range of hazards.
- It is also by necessity generalized to the attribute, and not specific to particular building characteristics (e.g., height, volume, etc.).
  - This is due to the range in applications, uses and consequences associated with the risk (i.e., application in low-rise or high-rise building; risk of structural failure of a structurally integrated panel (SIP) is not compared to risk of fire / smoke spread within a double-skinned façade).

Relative Fire Risk / Hazard Matrices



	Poses Potential ignition hazard	Poses Potential shock hazard	Potential explosion hazard	Poses Potential toxicity hazard	Readily ignitable	Burns readily once ignited	Contributes more fuel / increased HRR	Material affects burning characteristics	Fast(er) fire growth rate	Significant smoke production/hazard	Potential for shorter time to failure	Failure affects burning characteristics	Failure presents stability concern	Failure presents smoke spread concern	Material presents flame spread concern	May impact smoke/heat venting	May impact occupant evacuation	May impact FF water availability	May impact suppression effectiveness	May impact fire apparatus access	May impact FF access and operations	May impact containment of runoff	Relative risk level
Alternative Energy Systems																							
- PV roof panels	H	H				H																H		H
- Oil-filled thermals panels							H															H		H
- Wind turbines	M	M																				H		M
- Hydrogen fuel cells						H	H																	H
- Battery / energy storage systems	M	M	H	M	H	H	M	H	M	H														H
- Cogeneration systems							H																	M
- Wood pellet systems						H	H																	M
- Building integrated PV	M	M				M																		M
- Solar radiance concentration																								
Site Issues																							
- Permeable concrete systems																					H	M	H
- Permeable asphalt paving																					H	M	H
- Use of pavers																					H	M	H
- Extent (area) of lawn																					M	M	M
- Water catchment / features																						M	M
- Vegetation for shading																				M	M		M
- Building orientation																				M	M		M
- Increased building density																				M	M		M
- Localized energy production																						M	M
- Localized water treatment																						M	M
- Localized waste treatment																						M	M
- Reduced water supply																					M	M	M
- Hydrogen infrastructure			M																				
- Community charging stations	M	M																					
- EES fuel loads / hazards	H	H	H			M	H			H										H		H	H
- EV fuel load / hazards	H	H	H			M	H			H										H		H	H
- Propane vehicle hazards			H			M	H			H										H		H	H
- Fuel cell vehicle hazards	H		H			M	H			H										H		H	H
- Bicycle storage impact exits																				M			M
- Reduced street widths																				M		M	M
- Densification																				M		M	M
- Exterior EV chargers	M	M																					M

Risk Ranking Key

Low or N/A		Presents a low risk when unmitigated or is not applicable to the listed attributes
Moderate	M	Presents a moderate risk when unmitigated.
High	H	Presents a high risk when unmitigated.

Relative Fire Risk / Hazard Table

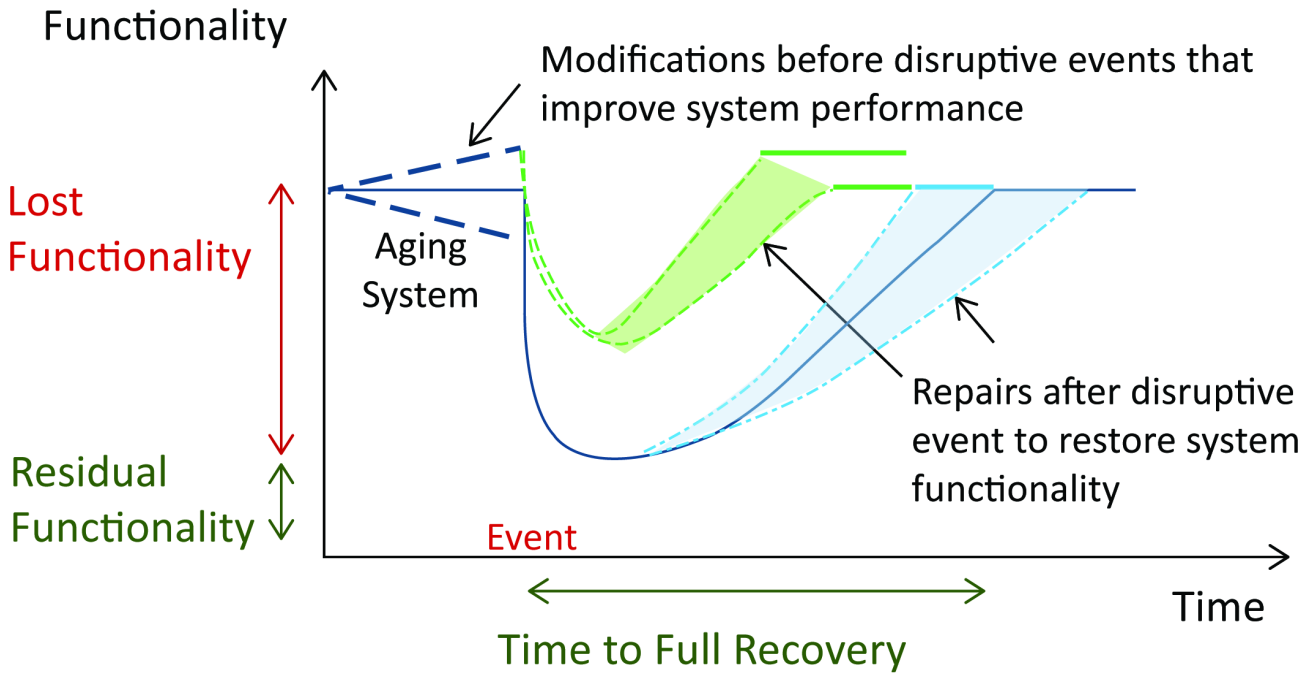
Exterior Materials and Systems			
Structural integrated panel (SIP)	If fail, insulation can contribute to flame spread, smoke production and fuel load.	High	Approved / listed materials. Assure proper sealing of panels. Take care during installation, including retrofits, relative to potential sources of ignition.
Exterior insulation & finish (EFIS)	If fail, insulation can contribute to flame spread, smoke production and fuel load.	High	Approved / listed materials. Assure proper sealing of panels. Take care during installation, including retrofits, relative to potential sources of ignition.
Rigid foam insulation	Can contribute to flame spread, smoke and toxic product development and fuel load.	High	Fire resistive barrier (e.g., fire rated gypsum). Approved / listed materials. Flame retardants. Sprinklers.
Spray-applied foam insulation	Can contribute to flame spread, smoke and toxic product development and fuel load.	High	Fire resistive barrier (e.g., fire rated gypsum). Approved / listed materials. Flame retardants. Sprinklers.
Foil insulation systems	Can contribute to shock hazard for installers. Can contribute to flame spread and fuel load.	High	Fire resistive barrier (e.g., fire rated gypsum). Approved / listed materials. Sprinklers.
High-performance glazing	Can change thermal characteristics of compartment for burning. Can impact FF access.	Moderate	Sprinklers. Assure adequate FD access. Assure mechanism for FD smoke/heat venting. Approved / listed materials.
Low-emissivity & reflective coating	Can change thermal characteristics of compartment for burning. Can impact FF access.	Moderate	Sprinklers. Assure adequate FD access. Assure mechanism for FD smoke/heat venting. Approved / listed materials.
Double-skin façade	Can change thermal characteristics of compartment for burning. Can impact FF access. Can present 'chimney' for vertical smoke and flame spread if not properly fire stopped.	Moderate	Appropriate fire stop between floors. Sprinklers may have some benefit (sprinklered building). Assure mechanism for FD smoke/heat venting. Approved / listed materials.

Tabular Representation of Attribute, Hazard, Concern Level and Potential Mitigation (Meacham & McNamee, 2020)

Resilience

The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.

Plan upfront to minimize future loss, disruption and cost

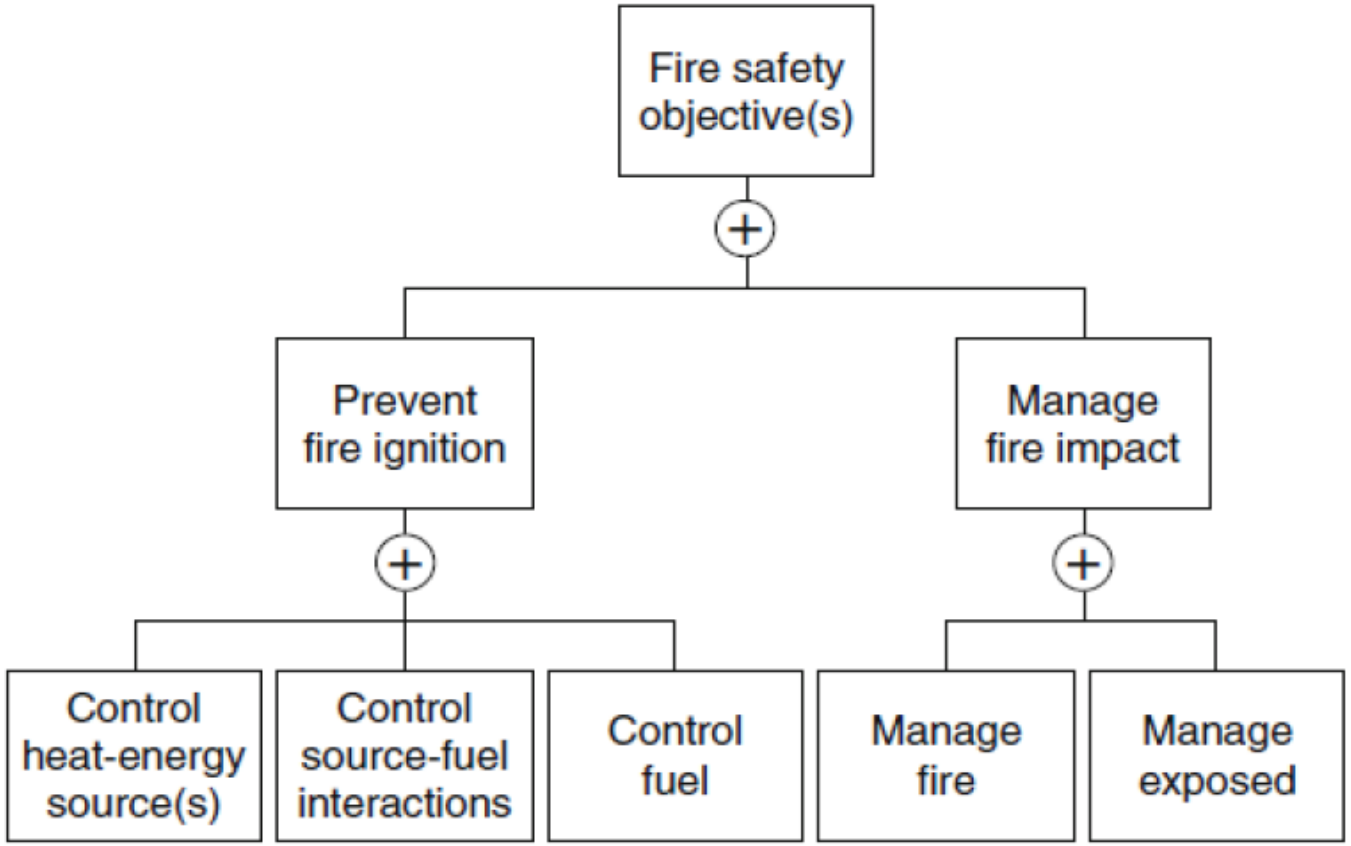


Meacham, B.J. (2018). *Building Community Resilience through Modern Model Building Codes*, ICC, Washington, DC.

Resilience Strategies for Buildings

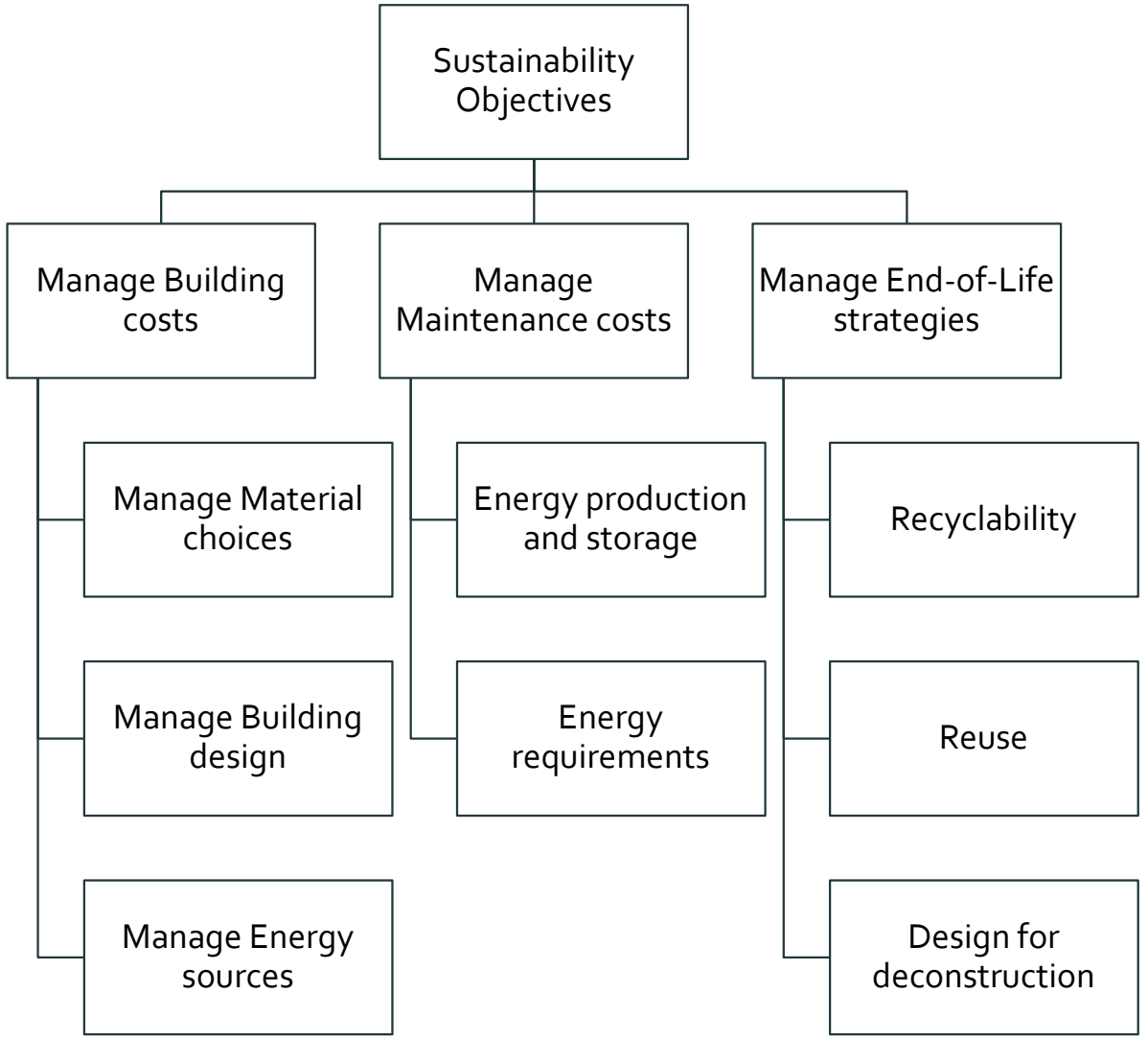
- A 'defense in depth' mindset
  - Use of multiple / redundant / more robust systems and approaches to reduce the potential for 'single point of failure' to result in unacceptable performance
- A holistic, multi-hazard approach
  - Eliminate the silos and better integrate building performance analysis across the disciplines, e.g., structural, energy and fire performance
- A risk-informed performance-based approach
  - Stop assuming single events only and more explicitly address range of scenarios that could occur, addressing uncertainty, variability, cost and safety issues

Fire Resilience Strategies for Buildings



NFPA 550 (2017). Fire Safety Concepts Tree. NFPA. Quincy. MA

Sustainability Strategies for Buildings



Sustainability & Fire Resilience – Competing Objectives?

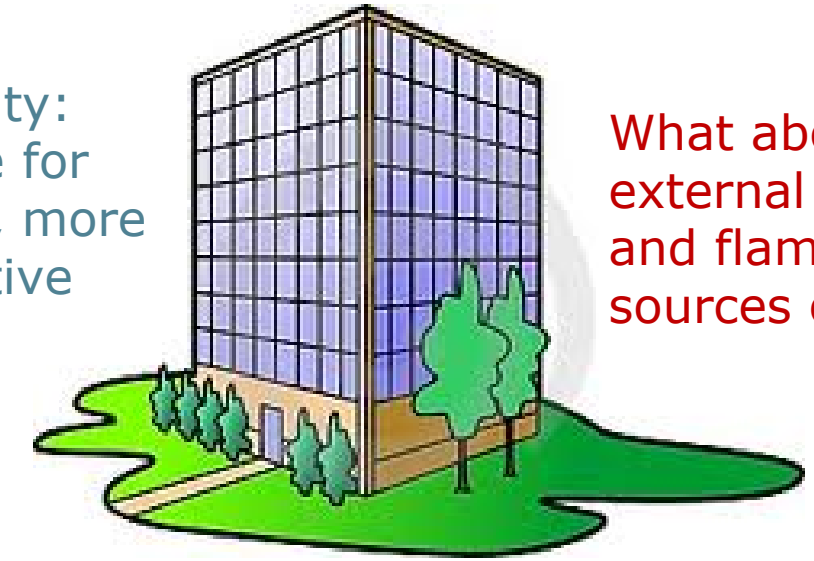
- There is a potential for 'competing objectives' with respect to sustainability and fire resilience
- Where known, the building regulatory system (building code, fire code, electrical code, standards) does rather well in facilitating achievement of both
- Potential for fire hazards and risks can result with introduction of new materials, systems and features (e.g., ESS), for which fire performance may not be well understood, especially in complex systems (e.g., façade systems)
- Extra-regulatory mechanisms (e.g., rating schemes) may inadvertently introduce unintentional risks / hazards, especially existing buildings

Sustainability & Fire Resilience – Competing Objectives?

Zoning: High density building, shading of buildings…

What about fire spread risk and fire service access?

Energy sustainability: Double skin façade for natural ventilation, more insulation, alternative energy source, …

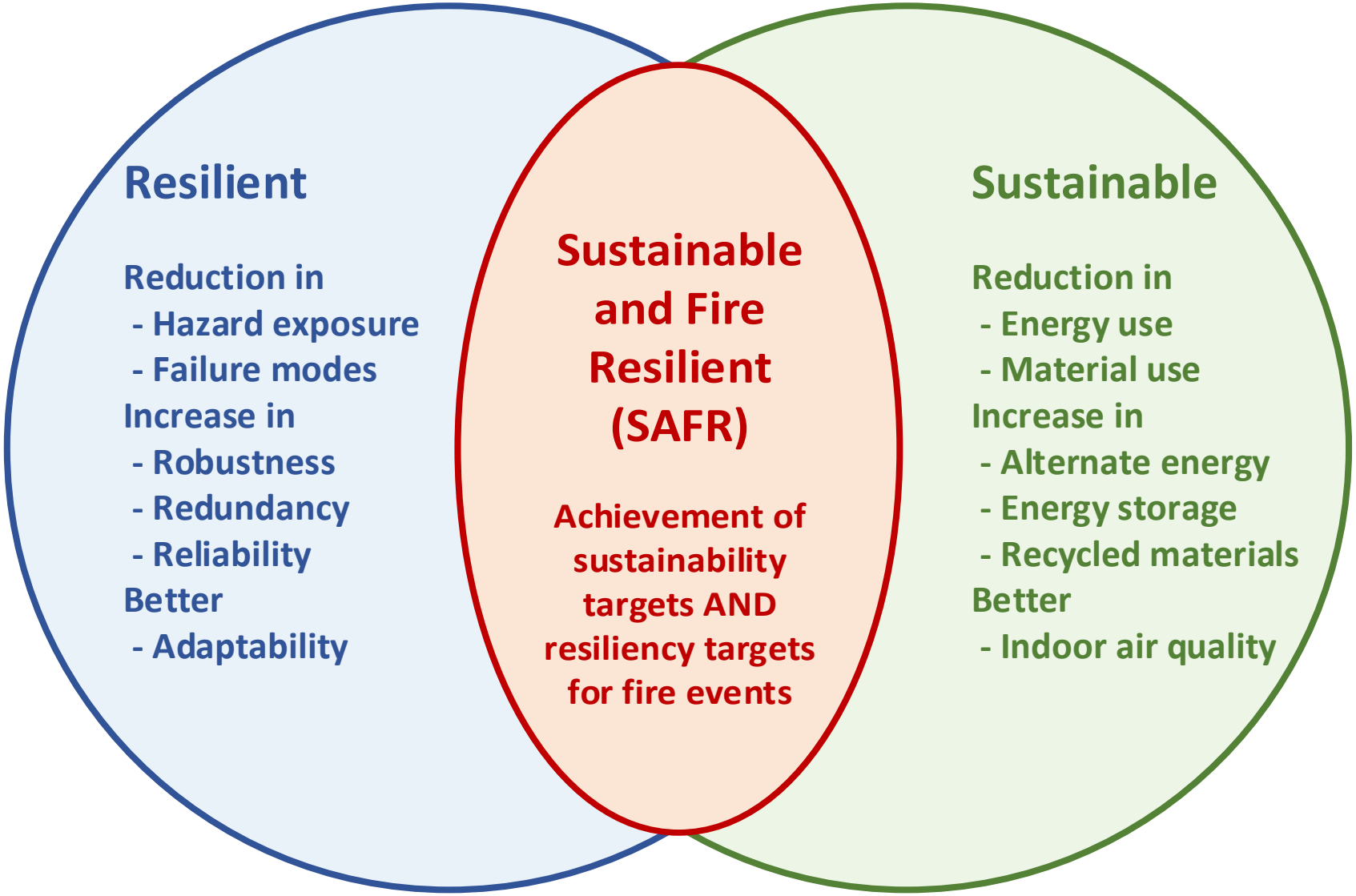


What about internal and external spread for smoke and flame, potential sources of ignition, …?

Material sustainability: less massive structural members, more timber, …

What about reduced resistance to fire / structural stability during fire?

Sustainable And Fire Resilient Built Environment (SAFR-BE)



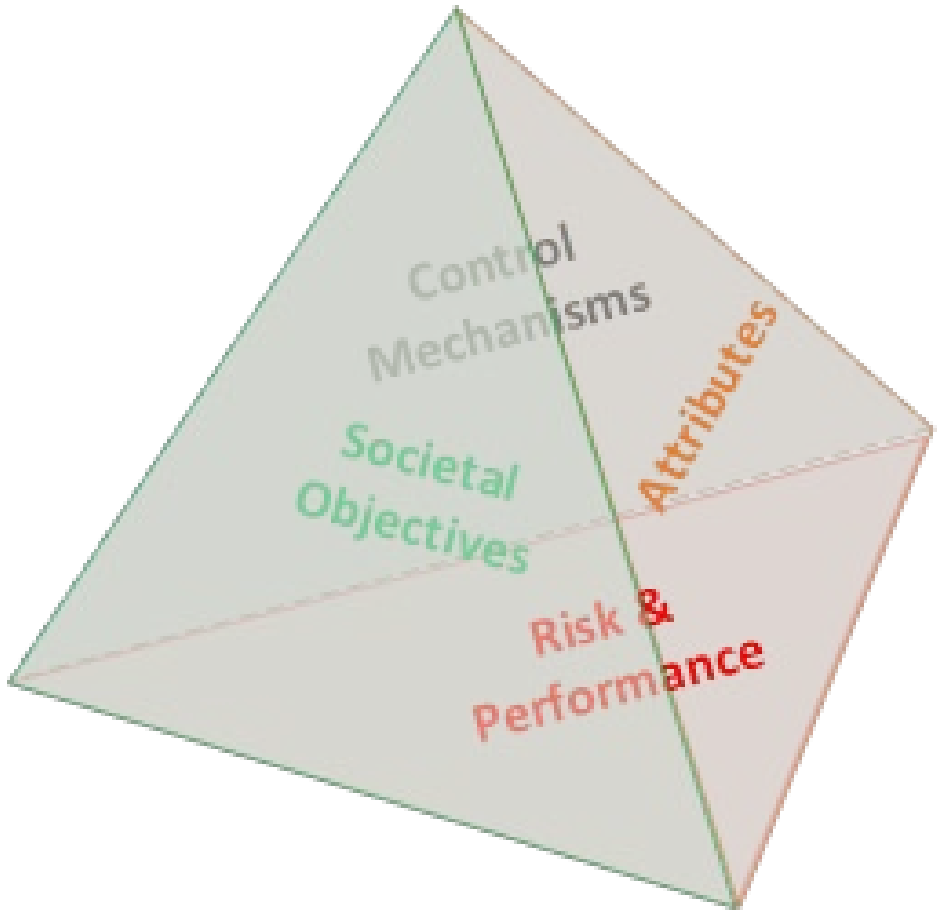
Meacham, B.J., and McNamee, M. (2020). Fire Safety Challenges of 'Green' Buildings and Attributes, Fire Protection Research Foundation, Quincy, MA, USA.

Sustainable And Fire Resilient Built Environment (SAFR-BE)

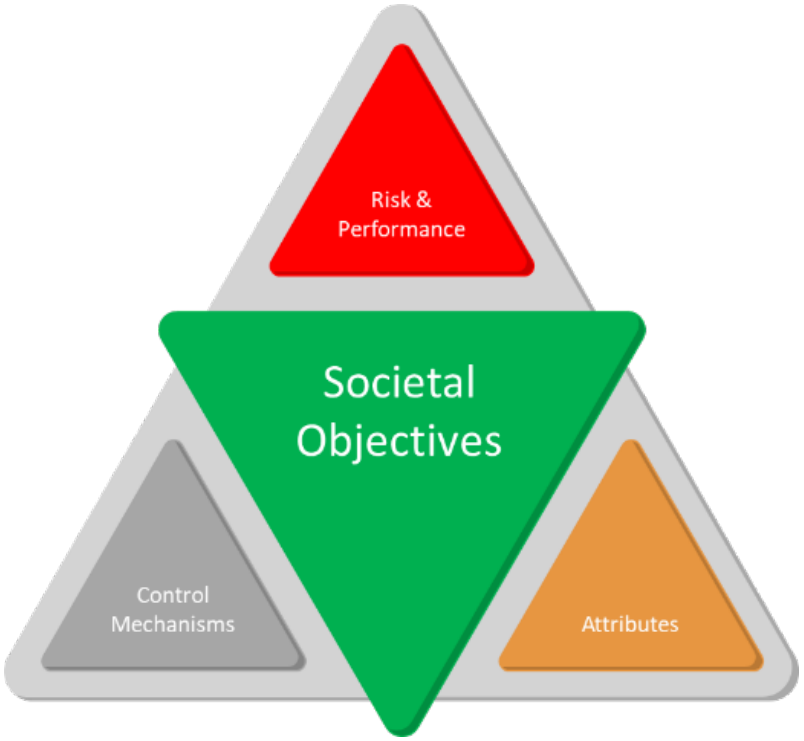
- Exemplar SAFR-BE Strategies
  - Minimize material waste while maintaining adequate FR of structure (optimize, including fire impact)
  - Less, or better protected, combustible material use
  - PV/ESS systems safety controls
  - Thermal barriers between PVS / ESS and building elements
  - Dual-purpose sensors (e.g., CO/CO_2)
  - Automatic suppression (sprinklers)
  - 'Green' credit for fire risk reduction
  - *Balanced, risk-informed and performance-based approach*

The future of the built environment

- Balancing risk & performance in terms of
  - societal objectives (to create modern, ‘green’ buildings which do not endanger our climate);
  - the attributes of the buildings and communities which express these societal objectives (materials, systems and design features); and,
  - control mechanisms that are put in place to ensure that these buildings and communities are fire safe (regulations, standards and guidelines).



Meacham, B.J. and M.M. McNamee, *Fire Safety Challenges of 'Green' Buildings and Attributes*. Research Report, 2020, Fire Protection Research Foundation: Quincy, USA.

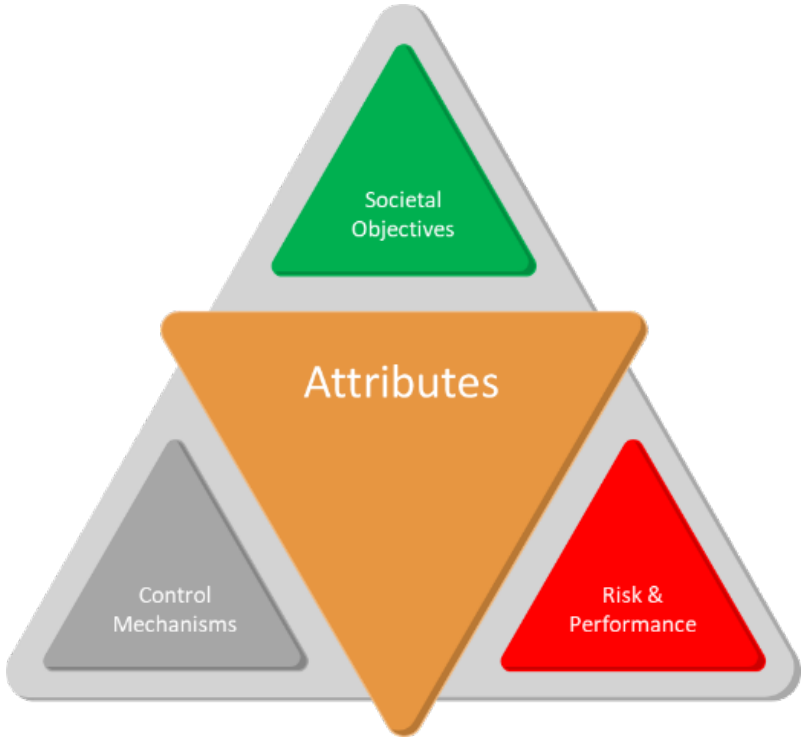


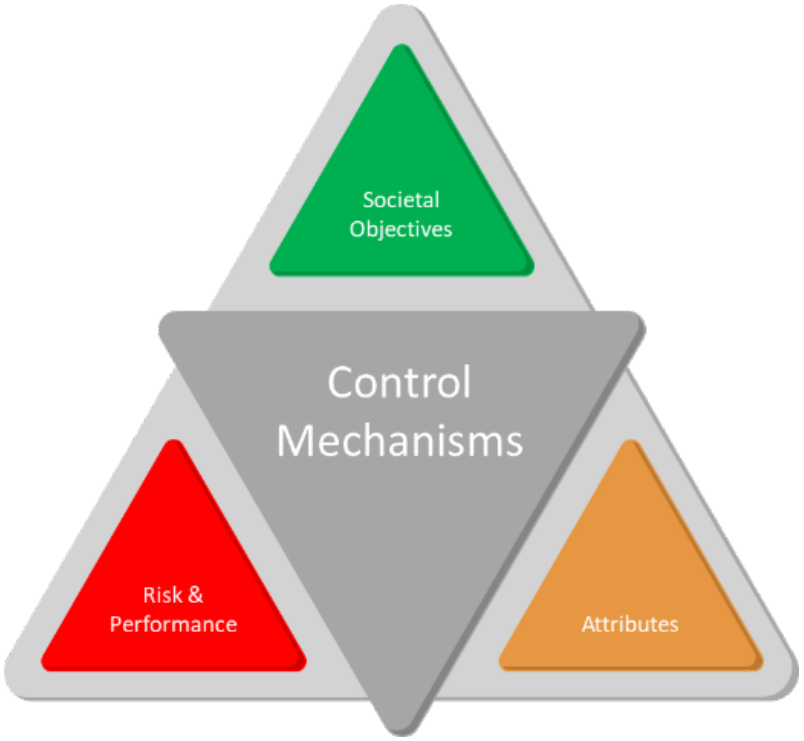
Analysis & Research Needs – Societal Objectives

- Need to consider all dimensions of sustainability
- Context is key – 'green' buildings do not exist in isolation, while sustainability and resiliency solutions are highly context dependent
- SAFR-BE concept can be applied both for new AND existing buildings
- Need new holistic models building on all aspects of sustainability and resiliency

Analysis & Research Needs – Attributes

- New materials, products and systems developed constantly
- Need for focus on safety and resiliency during the development process
- Processes need to be developed for repurposing material, products and systems for the adoption of greater recycling of material and products during the life-cycle of a building





Analysis & Research Needs – Controll mechanisms

- Testing, inspection and certification
- Reliance on performance based evaluation rather than lists of accepted and banned products or materials
- Clear need for systems to become more pro-active and reflect socio-technical systems approach

Conclusions & Future Work

- Integration of 'green' (sustainable) building attributes into fire incident reporting systems.
- More robust and appropriate test methods, which yield engineering data, for assessment of material, component and systems performance.
- Integration of the need for fire performance consideration into 'green' (sustainable) materials, technologies and features research and development.
- Robust risk and performance assessment methods and tools, which are founded on broad expert stakeholder knowledge and experience, available data, and expert judgment where data are lacking.

Conclusions & Future Work

- Robust risk and performance assessment methods and tools, which are founded on broad expert stakeholder knowledge and experience, available data, and expert judgment where data are lacking.
- Better tools for holistic design and performance assessment, taking advantage of BIM and other technologies that are defining the future of the construction market.
- Transition to more holistic, socio-technical systems approaches for building regulatory systems, which consider the diversity of societal and market objectives for building design, construction and lifetime operation.
- Further development and articulation of the SAFR buildings concepts and its societal and economic benefits.

Conclusions & Future Work

- There is much to be done, and it is important to keep fire safety at the forefront of developments in sustainable technologies and solutions, to create a more sustainable and fire resilient built environment.

Acknowledgements

I extend my sincere appreciation to my project collaborator, Brian Meacham, and to the FPRF for giving us the opportunity to conduct this project.

Two topics included in our work but not covered today:

- Regulatory landscape
- Firefighter materials

Thanks for your time and interest! Any questions?

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https://www.nfpa.org/~/media/Files/News%20and%20Research/Fire%20statistics%20and%20reports/Building%20and%20life%20safety/RFGreenBuildings2020.pdf