Chapter 5
Complexity of Sustainable and Resilient Building Design and Urban Development

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5.1 Introduction

Recent scientific research has established that climate change is primarily due to human activities that produce heat-trapping gas emissions. These emissions are mostly a result of burning fossil fuels, changing land use, deforestation, and other activities. Research also shows that among all human activities contributing to climate change, the construction and operation of buildings are among the most energy, pollution, and resource intensive. In the USA alone, buildings and their operations consume three billion tons of raw materials, 40% of the nation's total energy, and 77% of its electricity use each year. Materials utilized in constructing buildings have high embodied energy, high carbon emissions, and high levels of toxins and pollutants in their production cycle (UNEP 2007). It is estimated that buildings contribute as much as one-third of total global greenhouse gas (GHG) emissions primarily through the use of fossil fuels during their operational phase (UNEP 2009).

It is widely recognized that climate change impacts the natural and the built environment leading to grave socioeconomic and health problems (Portier et al. 2010). The impact on natural environments has multiple dimensions ranging from stressing the vulnerable ecosystems to water and food resources, eventually affecting all living things. The impact on the built environment is also substantial. This includes deterioration of buildings and urban infrastructure due to extreme events, high temperatures, and sea level rise leading to loss of life and destruction of public and private property. Impacts occurring now affect water, energy, transportation, agriculture, ecosystems, and health, but they are expected to intensify and increase in the future (Karl et al. 2009).

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Given the sizable contribution of the building industry to greenhouse gas emissions, enhancing the capacity of the building industry to mitigate climate change is critical. Sustainable design and development strategies can lead to significant reductions in energy consumption as well as minimizing the carbon footprint of buildings. Using the National Institute of Building Sciences definition, this article considers sustainable development as design and construction processes that reduce or completely avoid depletion of critical resources like energy, water, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are livable, comfortable, safe, and productive (NIBS 2012).

Sustainable design and development is a complex undertaking requiring collaborations among many experts from diverse disciplinary backgrounds, significant investments in buildings and their infrastructure, and developing advanced design and decision support tools. In addition, sustainable development in itself will not ensure safety of our future. The existing GHG levels in the atmosphere will remain high for many years to come. Scientists from the National Oceanic and Atmospheric Administration have concluded that the current level of GHG in the atmosphere will remain 1000 years after stopping emissions (McGregor et al. 2013, 117). This clearly indicates that mitigation strategies to reduce GHG have been difficult to implement and will not eliminate our significant challenges.

Therefore, it is equally important to acknowledge the need for addressing the unavoidable climate change consequences by acting to manage risks and working to create a resilient built environment. Creating flexibility in design to accommodate anticipated conditions will reduce the vulnerability to impact. However, efforts and strategies for adapting to climate change should not undermine mitigation efforts for stabilizing GHG emissions. Sustainability and resiliency approaches and strategies can be enhanced when they are *mutually considered* and incorporated in the design and construction in the early stages of the process.

The following sections of this chapter provide an overview of the complex issues, current design, development processes, and barriers in achieving goals of sustainable and resilient built environments. The specific objectives of the chapter are to: (1) examine and reveal the scale and complexity of challenges in sustainable design and development, and identify a range of broad mitigation strategies, (2) examine vulnerabilities of buildings and their infrastructure to climate change and extreme events, broadly outlining adaptation strategies for resilience, (3) highlight synergetic benefits and conflicts between sustainable and resilient design strategies, and (4) describe traditional building design development and examine how new practices and technologies can foster the sustainability and resiliency of the built environment.

5.2 Sustainable Building Design and Construction

5.2.1 Climate Change Challenges

Recent design and construction standards for energy efficient and sustainable buildings are enhancing the practice of sustainable building design and development in the USA. However, the widespread and large-scale adoption of sustainable strategies has been slow. This slow rate is a consequence of a number of issues. First is the increase in demand for buildings in response to population growth. For example, the number of households in the USA grew nearly 40% (from 80 to 113 million) from 1980 to 2005, and the total area requirement for commercial buildings grew 35% from 1985 to 2004. These represent a combined increase of 70% in energy demand (US DOE 2008). The increased demand for building construction left little room for building industry to consider sustainability as a major element.

The second factor is that buildings with a high degree of energy efficiency in the USA are generally designed by a small group of elite architectural and engineering firms. Limited internal expertise, high cost, and time constraints are among major barriers to a wider adoption and use of sustainable design strategies for small and midsize companies. The third factor is the weakness of the current evaluation, rating systems, and benchmarking for sustainability of buildings. US rating systems, such as Leadership in Energy & Environmental Design (LEED), have been criticized on failing to significantly reduce energy consumption and do not compare well against other international rating systems (Spiegelhaulter 2008).

Finally, the current building design process is mostly reliant on the experience and expertise of the architects and the engineers involved in the process without access to any comprehensive decision support tools. Many design strategies are based on what has worked in the past without an examination of a wide range of other alternatives and possibilities. In addition, computer simulations to predict building performance are often carried out by fragmented simulations of various building systems in isolation, without a holistic approach or integration. This fragmented approach and the lack of adequate decision support system often lead to disregarding design strategies that may be significantly more appropriate and effective for sustainability (Hopfe 2009; Olusegun et al. 2001).

5.2.2 Mitigation Strategies

There are numerous strategies that can be used to reduce energy consumption and minimize the carbon footprint of buildings. However, these strategies are sometimes in conflict or may not align well with broader building objectives such as owners' priorities, building location, or the financial constraints of the project. This makes the process of building design a balancing act that requires input and guidance from multiple recourses.

To create an overall understanding of possible strategies to mitigation, Table 5.1 provides a series of design measures in relation to building design, urban form, and landscape systems. In this table, the strategies for building design are categorized into two subgroups of building configuration, and materials and assemblies.

Table 5.1 Sustainable design strategies

Building design		Strategies
Configuration	Building shape	Reduce surface to volume ratio, appropriate plan shapes for solar radiation, reduce exposed surface area
	Climate responsive design	Appropriate building orientation and siting, access to natural light and natural ventilation
Materials and assemblies	Low energy efficiency	Utilize thermally efficient materials and insulation, seal connections and joinery, use climate responsive facades and shading systems
	Low carbon footprint	Use low embodied energy and low embodied water materials
Urban form		*Strategies*
Density	Dense construction	Reduce vehicular travel miles, change zoning to discourage sprawl, provide incentives for living close to work, enhanced public transportation, use heat recovery systems
Diversity	Mixed-use building	Reduced vehicular travel miles, revise land use designations, provide incentives for high density and infill development, provide amenities in living and work proximity
Landscape systems		*Strategies*
Thermal efficiency	Solar heat gain moderation	Shield from solar heat using canopy shading, vegetated surfaces, green walls, green roofs, and earth sheltering
	Wind control	Landscape wind breaks, foundation planting, wind deflectors, and channels
	Pollution control	Use vegetated filter strips and suitable plants to remove water, soil and contaminants, and air pollution
Thermal efficiency	Solar heat gain moderation	Shield from solar heat using canopy shading, vegetated surfaces, green walls, green roofs, and earth sheltering
	Wind control	Landscape wind breaks, foundation planting, wind deflectors, and channels
	Pollution control	Use vegetated filter strips and suitable plants to remove water, soil and contaminants, and air pollution
Hydrological efficiency	Water conservation	Use low irrigation plant and efficient irrigation mechanisms
	Runoff mitigation	Use pervious pavements, green roofs, storm water planters, bioswales, detention and retention basins
	Wastewater management	Utilize surface and subsurface flow wetlands, use bioremediation systems

Table information is based on Best Practices in Sustainable Design authored by Vassigh et al. (2013), and Urban Form and Climate Change, Hamin and Gurran (2009)

Building configuration involves decisions about building geometry, volume, orientation, and the exposed surface area to the environment. Appropriate strategies for building configuration place a high priority on climatic conditions of the building site often leading to significant energy saving. These strategies prioritize the use of natural cooling, heating, and ventilation (passive controls) over the use of mechanical systems (active controls). They also emphasize the use of natural light over artificial lighting. For example, a building located in a cold climate with an elongated shape along the east and west axis and openings on the south side can utilize solar heat and access daylight, thus reducing energy demand.

Contrarily when designing in hot and dry climates, minimizing the building dimensions in the east–west direction reduces solar heat gain. In addition, placing building services such as elevators and stairs in the east–west direction blocks direct sunlight and creates buffer zones. Shallow floor depths in these climatic conditions provide ample daylight and maximize cross-ventilation and night cooling if the building openings are located on the long sides of the building to utilize prevailing winds.

Building materials and assemblies are another important factors in determination of building performance. Materials with high thermal efficiency used in building enclosures control heat gain and heat loss significantly. For example, wood has a higher resistance to heat transfer than concrete and steel. Therefore, using wood in building facades could be an effective strategy in particular climatic conditions. Some materials such as concrete, masonry, or stone have the capacity to absorb and store solar heat. When properly used, they can absorb heat energy deep into their mass during the day and slowly release it during nighttime.

There are also new technologies and materials such as phase change material (PCM) that can store energy and release it at a later time. PCM can be incorporated into wallboards, roofs, ceiling, and floors to passively cool or heat buildings (Vassigh et al. 2013). It is critically important to have all building connections sealed off to prevent a higher rate of heat transfer at connections, particularly in cold climatic zones. Using airtight connections and placing insulation materials in vulnerable areas often achieve this. Using airtight connections also helps with endurance of the building exterior materials as it prevents moisture accumulation at the connection vicinity where the hot and cold air meets.

Another important aspect of material use in buildings is the evaluation of their environmental impact. Construction materials use energy and water in their production and transportation to the building site. Embodied energy is defined as the energy used during the entire life cycle of a material including the energy used for manufacturing, transporting, and disposing (Lippke et al. 2004). Similarly, embodied water indicates the amount of water used to produce, transport, and dispose of a material. As indicated in Table 5.1, selecting materials with lower embodied energy and embodied water will reduce the carbon footprint of buildings. Unfortunately, embodied energy and water are often overlooked in lieu of other considerations.

The next category of strategies for sustainable development addresses the larger context of development in the urban form. Table 5.1 subdivides urban form into two closely related subcategories of dense construction and mixed-use buildings. Constructing buildings, neighborhoods, and larger communities in densely configured patches has multiple benefits. Density reduces energy used for commuting significantly. When properly coupled with designing mixed-use building strategies, it creates incentives for people to commute less as they are able to walk to work and amenities. In addition, dense development makes the use of public transit more feasible. However, to achieve this, the zoning codes and planning priorities should be significantly revised and incentives for developers and all other involved parties should be expanded. Dense development should be carefully planned as it may be in conflict with other strategies that prioritize reducing traffic and air pollution.

The last section of Table 5.1 lists some of the numerous and effective sustainable strategies that can be provided by landscape systems. Divided into thermal efficiency and hydrological efficiency subcategories (Vassigh, Ozer, Spiegelhalter 2013), these strategies can be applied at the small scale of individual buildings as well as the large scale of the urban environment and beyond. Landscape systems can shield buildings from solar heat. Using canopy shading, vegetated surfaces, green walls, and roofs can moderate solar heat gain. In addition, landscape systems protect buildings from wind and facilitate natural ventilation.

Landscape systems can be used to mitigate air, water, and soil pollution. For example, large-leaved indigenous evergreens mitigate airborne pollution. Vegetative filter strips such as orchards, vineyards, and row crops remove pollutants from runoff water while providing some degree of resistance to soil erosion. Certain species of plants remove or degrade contaminates from soil and water through their internal process, thus providing an economically viable method to control pollution (Kumar et al. 2013).

Significant freshwater conservation can be achieved by incorporating hydrological sensitive landscape design solutions. Using low irrigation plants and efficient irrigation mechanisms in buildings and urban environments can lead to significant water saving. Recycling wastewater generated through buildings' functions (gray water) for watering garden and landscapes is also another increasing viable method for water conservation. Furthermore, landscape strategies can be used to develop ecological habitats for wildlife, absorb floodwaters, provide added recreational amenities, and improve aesthetics (Vassigh et al. 2013).

5.3 Resilient Building Design and Construction

5.3.1 Climate Change Challenge

Climate change is presenting new challenges to the built environment by increasing both the intensity and frequency of extreme events. High temperatures, sustained high winds, weather fluctuations, flooding, drought, and sea level rise set the context in which our buildings and their infrastructure must exist and remain usable.

These events generate significant stresses such as intensified wind impact on building structures, wind-driven rain intrusion into buildings through facades, storm surge, and intense flooding. In addition, the consequences of sea level rise on building systems, materials, and foundations can be devastating.

Generating public sector support in order to develop the appropriate actions for adaptation to climate change impacts has been difficult for a number of reasons: first, the public's disbelief and the lack of recognition of the risks and threats; second, the absence of appropriate risk assessment and decision-making support tools; third, the anticipated high cost of long-term benefits with little or no immediate payback; and finally, the lack of adequate and enforceable policies for building in new conditions.

Three sections of Table 5.2 provide an overview of a series of adaptation strategies for climate change. It categorizes various adaptive approaches for three major climate change impacts including rising temperature, storms and hurricanes, and sea level rise. Measures for addressing each impact are subdivided into three interconnected scales of buildings, community, and the urban environment.

Table 5.2 lists a number of strategies for combating higher temperatures at the building scale. These strategies revolve around extensive use of green walls and green roofs, trees, and vegetated surfaces, in order to provide thermal insulation and shade to reduce temperature. Designing to maximize natural ventilation in buildings

Table 5.2 Resilient Design and Development for Buildings

Climate change impact	Community strategies
Rising temperature	✓ Design for Natural Ventilation and Passive Cooling ✓ Use Green walls, Green roofs, Trees and Vegetated Surfaces ✓ Provide Thermal Insulation, and Canopy Shading ✓ Minimize the Exterior Surface Area
Storms and hurricanes	✓ Enhance and Reinforce Building Foundations to Provide Resistance to Hydrostatic Pressure ✓ Use Rigid Connections and Reinforce Joinery to Increase Resistance to Wind load ✓ Use Simple Building Shapes and Plan to increase Wind Resistance ✓ Use Structural Separation to Divide Building to Wings Which Act independently Under Wind Load ✓ Minimize Exposed Surface Area to Prevailing Winds ✓ Water Proof Building Foundations to Provide Protection from Storm Surges and Flooding ✓ Use Water Resistant Materials in Building Facades to Pro-tects Against Wind Driven Rain and High Humidity ✓ Design Buildings Ground Level to Allow Passage of Flood Water
Sea level rise	✓ Use Flood Walls, and Compact Earth Fills ✓ Raise Buildings on Piles Above Flood Levels to Protects Water Damage ✓ Move Building Service Equipment to Higher Floor ✓ Encourage Multistory Construction to Provide Additional Space if Necessary to Abandon Ground Levels

is another way of combating high temperatures. However, as the temperature rises, the use of outside air for cooling building's interior space becomes less feasible.

Measures for resilient construction for extreme events such as storms and hurricane for buildings include simpler configurations that offer better resistance to high winds. Minimizing exposed surface area and using continuous joinery and connections in buildings are among other strategies to increase resistance to the wind impact. Measures to combat water from storms and hurricanes in buildings include water-proofing foundations, use of water-resistant materials in building facades to protect against wind-driven rain, and designing ground levels to allow passage of floodwater. Methods to address the impact of sea level rise in buildings include construction of sea walls, using compacted earth fills and raising buildings on piles above the flood levels. In addition, relocating all building services and mechanical equipment to higher floors eliminates water damage in storm surge or flooding.

The measures at the community scale are listed in Table 5.3. Using landscape strategies, reflective roofs, and reduced impervious surfaces are among measures to remediate high temperature. To control the impact of storms and hurricanes, clustered planning of buildings can be very effective. Grouping buildings in close proximity in staggered patterns reduces wind-tunneling effect, thus controlling damage.

High-density development, listed in Table 5.1 as a sustainability measure, is also a highly effective resiliency approach to manage storm water. Dense construction can reduce impervious surfaces such as roads, parking lots, and paved sidewalks that cannot absorb the storm runoff and can be easily flooded. Measures for combating sea level rise in low-lying and vulnerable areas include moving entire communities to higher elevations or retreat from the area.

Table 5.4 addresses appropriate measures at the urban scale. The urban environment has a microclimate condition called urban heat island effect, which is a local increase in temperature due to high density of buildings with hard surface, high density of transportation activities, and generation of wasted heat from

Table 5.3 Resilient design and development for community

Climate change impact	Community strategies
Rising temperature	✓ Use reflective roofs and street pavements ✓ Reduced impervious surfaces by grouping buildings in close proximity ✓ Utilize trees to provide canopy shading
Storms and hurricanes	✓ Promote clustered planning to reduce wind-tunneling effect ✓ Utilize detention basins to hold storm ✓ Water
Sea level rise	✓ Elevate buildings and infrastructures ✓ Retreat from low-lying areas

Table 5.2 information is based on Best Practices in Sustainable Design authored by Vassigh et al. (2013), and Urban Form and Climate Change, Hamin and Gurran (2009)

buildings. As temperature rise heightens this condition, utilizing trees and green belts moderates the heat island effect. In addition, using heat recovery systems to remove wasted heat from buildings and converting usable energy is increasingly a technologically and economically viable solution.

To control the impact of storm and hurricane-generated water, the reduction of impervious surfaces can control runoff water. In addition, constructing treatment wetlands for cleansing storm water and placing green space along flood lanes are appropriate measures.

Among strategies to protect the urban environment from the impact of sea level rise in the costal zones reestablishing sand dunes is critical. According to FEMA, due to over development some sand dunes have been completely destroyed. Rebuilding sand dunes and preserving them with coastal vegetation can protect large areas further inland, which enhance the appearance of the beaches (FEMA 2007). Other measures include creating earthen levees, beach nourishment to replace eroding beaches, increased coastal set back requirements, and elevating critical infrastructure (Hamin and Gurran 2009).

The discussion above offers a range of possible mitigation and adaptation strategies for climate change. However, providing an expansive list of measures to address every impact of climate change on the built environment is not the ultimate goal and is beyond the scope of this article. The objective here is to reveal the scale and complexity of issues.

The following sections shift the focus on building design and development processes and examine how to implement these strategies.

5.3.2 Mitigation Strategies

Three sections of Table 5.2 provide an overview of a series of adaptation strategies for climate change. It categorizes various adaptive approaches for three major climate change impacts including rising temperature, storms and hurricanes, and sea level rise. Measures for addressing each impact are subdivided into three interconnected scales of buildings, community, and the urban environment.

Table 5.2 lists a number of strategies for combating higher temperatures at the building scale. These strategies revolve around extensive use of green walls and green roofs, trees, and vegetated surfaces, in order to provide thermal insulation and shade to reduce temperature. Designing to maximize natural ventilation in buildings is another way of combating high temperatures. However, as the temperature rises, the use of outside air for cooling building's interior space becomes less feasible.

Measures for resilient construction for extreme events such as storms and hurricane for buildings include simpler configurations that offer better resistance to high winds. Minimizing exposed surface area and using continuous joinery and connections in buildings are among other strategies to increase resistance to the wind impact. Measures to combat water from storms and hurricanes in buildings include water-proofing foundations, use of water-resistant materials in building facades to protect against wind-driven rain, and designing ground levels to allow passage of floodwater. Methods to address the impact of sea level rise in buildings include construction of sea walls, using compacted earth fills and raising buildings on piles above the flood levels. In addition, relocating all building services and mechanical equipment to higher floors eliminates water damage in storm surge or flooding.

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High-density development, listed in Table 5.1 as a sustainability measure, is also a highly effective resiliency approach to manage storm water. Dense construction can reduce impervious surfaces such as roads, parking lots, and paved sidewalks that cannot absorb the storm runoff and can be easily flooded. Measures for combating sea level rise in low-lying and vulnerable areas include moving entire communities to higher elevations or retreat from the area.

Table 5.4 addresses appropriate measures at the urban scale. The urban environment has a microclimate condition called urban heat island effect, which is a local increase in temperature due to high density of buildings with hard surface, high density of transportation activities, and generation of wasted heat from buildings. As temperature rise heightens this condition, utilizing trees and green belts moderates the heat island effect. In addition, using heat recovery systems to remove wasted heat from buildings and converting usable energy is increasingly a technologically and economically viable solution.

To control the impact of storm and hurricane-generated water, the reduction of impervious surfaces can control runoff water. In addition, constructing treatment wetlands for cleansing storm water and placing green space along flood lanes are appropriate measures.

Table 5.4 Resilient Design and Development for the Urban Environment

Climate change impact	Community strategies
Rising temperature	✓ Use Trees and Green Belts to Create Shade ✓ Utilize Heat Recovery Systems to Remove Wasted Heat from Buildings and Convert to Usable Energy
Storms and hurricanes	✓ Reduce Impervious Surfaces to Control Runoff Water ✓ Utilize Constructed Treatment Wetlands for Cleaning Storm Water ✓ Use Green Space Along Flood Lanes
Sea level rise	✓ Reestablishing Sand Dunes and use Earthen Levees ✓ Use Beach Nourishment to Enhance Eroding Beaches ✓ Increase Coastal Set Back Requirements ✓ Elevate Critical Infrastructure ✓ Retreat From Low Lying Areas

Among strategies to protect the urban environment from the impact of sea level rise in the costal zones reestablishing sand dunes is critical. According to FEMA, due to over development some sand dunes have been completely destroyed. Rebuilding sand dunes and preserving them with coastal vegetation can protect large areas further inland, which enhance the appearance of the beaches (FEMA 2007). Other measures include creating earthen levees, beach nourishment to replace eroding beaches, increased coastal set back requirements, and elevating critical infrastructure (Hamin and Gurran 2009) (Table 5.4).

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5.4 Design and Development Process: The Case for Data-Driven Integrated Practice

Building design, development, and construction is an interdisciplinary effort. Architects, engineers, planners, construction experts, landscape designers, and other stakeholders engage in a process that involves understanding many issues, making difficult decisions, and balancing a number of competing concerns. The overlay of sustainable and resilient design considerations creates another layer of complexity that makes it difficult to address with the existing processes and tools. For successful outcomes, experts are in need of appropriate practice processes, decisions support tools, and access to readily usable data.

The traditional process in the design, engineering, and construction of buildings follows a linear pattern, moving the building project from one expert to another (Toth et al. 2009). Most midsize to large building projects begin with an agreement between the client and an architectural firm. Architects, traditionally in charge of building design, begin with tackling the client's needs and critical requirements such as building program and function, siting considerations, aesthetic goals, and the financial aspects of the design. Often, this involves investigation of a range of possible alternatives-based precedent and the experience of the firm or the architect. Possible alternatives are discussed, examined, and analyzed using computer simulation applications, and a single design proposal is selected. At this stage, the critical decisions such as building form, orientation, materials, and systems are mostly concluded and the project is turned over to the engineers. Engineers follow to resolve technical issues and design various building systems including structural, mechanical, and electrical systems. Once the engineering stage is completed, the project is passed to the construction experts.

Decisions made in the earliest stage of design have the greatest impact on building performance, construction, operation cost, and the environmental footprints of buildings (Toth et al. 2009). When structural engineers, mechanical engineers, and construction experts get involved after significant decisions have been made, their contributions are reduced to problem solving rather than providing innovative insights. Without collaborative engagement of all experts from the beginning of the project and input from various perspectives, innovative design possibilities are squandered and many opportunities to create synergetic benefits are lost. Integrating design and engineering decisions at the early stages when the proposal is still malleable (Tavares and Martins 2007) is critical to the building performance and sustainability.

Recent research by the National Institute of Building Sciences and others shows that the most resource efficient, best performing, and environmentally sustainable buildings are designed using integrated practice. Integrated practice is the process by which engineers, architects, construction experts, and other stakeholders begin working together at the conception of a project to create synergy among various building systems and improve overall building performance. When all experts collaborate early and effectively at the start of a building project, their collaboration produces better designed, more efficient, and lower cost buildings (NIBS 2008). Integrated practice also leads to design of resilient buildings. Early planning through integrated practice can reduce the impact of a disruptive event and the duration of their impacts (NBIS 2015).

Promoting integrated practice has been recognized by the American Institute of Architects (AIA) as one of the central challenges facing the profession and one of the most important ways to improve building performance, cost, and environmental impact. The AIA 2030 Commitment challenged the profession to achieve the goal of designing carbon neutral or no greenhouse gas emitting energy, buildings in the USA and *identified the practice of Integrated Design as the primary vehicle to attain this goal* (AIA 2007).

However, moving toward integrated practice has been very slow. There are no comprehensive and effective communication and decision support tools to facilitate this process. Although there are numerous computer applications used for performance simulation, documentation, management, and project delivery, there has not been much effort toward developing tools that can assess the interdependency and dynamic interactions of various decisions and discipline-specific constraints. As strategies are selected or proposed, there is a need to evaluate and compare their competing requirements based on concrete and validated data (McCarney 2009).

In addition, there is also a lack of access to the relevant and critical information that could facilitate decisions made by groups of experts. Current codes, standards, and practices use existing data that assumes the future will be similar to the past (Larsen et al. 2011). Immediate access to curated data on regional climate and its impacts on the environment is a key element for integrated practice

Technological advances in hardware, storage, and software have significantly increased the ability to capture, curate, analyze, and visualize vast amount of data. Recent technologies offer new possibilities to use data for fundamentally changing the way buildings and urban environments are designed and functioned. This is particularly true of climate change data such as predictions of storms, temperature changes, humidity, and sea level rise. In addition, compiling data from pervious buildings and their performance can highlight what has worked in the past and inform decisions for the future based on validated data and informed projections, thus providing a new way of using precedents and past experiences.

5.5 Conclusion

The impact of climate change will significantly challenge the built environment. The impact is expected to continue and intensify in the future, substantially changing our way of life. This chapter described some of these major challenges and provided an overview of strategies and measures to mitigate major impacts. Focused on buildings, sustainability, and resiliency of the built environment was discussed in three related scales of buildings, communities, and urban environments. By highlighting and examining a range of key issues, vulnerabilities, strategies, and processes, the article revealed the complexity of design and development of the built environment, demonstrating the need for decision support tools and a data-driven approach.

As discussed, building design, development, and construction is an interdisciplinary endeavor and effective collaboration among various domain experts is critical to the sustainability and resiliency of the environment. The architectural profession identified integrated practice as the appropriate venue for interdisciplinary collaboration to enhance building performance, foster innovative solutions, and realize synergetic benefits from combining resources in buildings. However, integrated practice must be supported with appropriate tools in order to make it a feasible practice for the majority of design and construction firms. Developing decision support tools based on captured and curated data is a necessary but missing element in the success of integrated practice. With the increasing role of data in environmental sciences and technological advances in simulations and data visualization, developing intelligent decision support tools is within reach.

Integrated practice appropriately supported can move the building design process beyond relying on the experience and expertise of a singular firm, architect, or engineer by utilizing data for validation of the approach. With climate change in full swing, tools that inform practical decisions and facilitate collaborative problem solving must be central to any step forward in moving toward a sustainable and resilient built environment.

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