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# BUILDING RESILIENCE:
## *A Framework for Assessing and Communicating the Costs and Benefits of Resilient Design Strategies*

**Fiona Wholey,** *fiona.wholey@perkinswill.com*


ABSTRACT

Increasing occurrences of natural disasters and effects of climate change are creating more pressure to design resilient buildings that can withstand and adapt to changing risks, while being sustainable and creating healthy environments. A key challenge to the implementation of resilient design is perceived viability and how to incorporate and communicate the long-term benefits into the equation.

This project, by the University of Minnesota Research Practices Consortium and Perkins+Will, aims to expand existing resilience frameworks to incorporate the changing risks from global warming and the importance of sustainability for designing resilient buildings. It seeks to examine how incorporating these discourses can help to reframe the discussion of resilient design from economic factors to one of benefits and reduced risks.

The methodology for the study is based upon analyzing an existing resilience assessment framework for disaster mitigation, and integrates sustainability and climate change factors to develop a more inclusive framework to evaluate building resilience. This framework is tested using two schematic buildings, an office and a hospital located in the Midwest and uses ReLi, the resilient action list, a resilience tool in development by Perkins+Will. The result of this research is a study of resilient design strategies examining their costs and benefits.


KEYWORDS: climate change, risk, sustainable design, financial viability

## 1.0 INTRODUCTION

Recent natural disasters, such as Hurricane Sandy, have illustrated the growing vulnerability of the built environment, a growing urban population, and more assets located in vulnerable places to a changing climate[1]. This combination of factors is raising the average yearly cost of disasters from $50 billion per year in the 1980's to just under $200 billion per year in the last decade[2]. The interest in designing places that can adapt and respond to these changing risks is increasing, which can be seen with resilience taking center stage at the AIA Convention in 2014[3] through to city plans, such as PlaNYC[4]. These events are helping to ensure that resilience is taken into account along with sustainability. While frequently the impetus for change and the charge to design for changing risk comes after a shock, many cities and organizations are beginning to look at how to design for social, economic, or physical resilience before disaster strikes.

The discussion on resilience has been predominately led by public organizations, such as the City of Chicago, or non-profit organizations including the Rockefeller Foundation and the USGBC. This is changing, as the financial and risk analysis for businesses are increasingly being examined, such as with the "Risky Business Project"[5] launched in 2013. The financial viability of designing for resilience is still a concern, increasing interest in the costs and benefits of resilient design. This paper examines the potential costs and benefits of designing for resilience. It looks at the capital costs for a project when incorporating resilient design strategies and also highlights the current research and studies on the benefits of those design strategies.

Even with this growing global and national interest in resilience, measuring resilience is elusive because it is dependent on context. In each context, whether it is at the scale of the city or a building site, there are different stressors to respond to and this impacts how resilience is measured or framed. For a city or building that is close to the waterfront, how it will respond to flooding or storm surges is essential for measuring its resilience whereas in seismic zones, it is how it responds to an earthquake. Considerations for resilience also include the social or economic stressors within a context. Rockefeller Foundation's "100 Resilient Cities"[6] reflects this variance in measurement and the impact of context. Each 'Resilient City' identifies different stressors and issues to respond to. In Chicago, the key stressors are related to the built environment with infrastructure failure and flooding, in addition to the social concerns of endemic crime. Whereas New York's focus is on rising sea levels, coastal erosion, transportation, and heat waves. This difference in risk is reflected in both New York's and Chicago's city plans. New York's approach to resilience, with the PlanNYC[7], has a strong emphasis on coastal protection of assets, whereas Chicago focuses on its primary stressors of climate adaptation with the Chicago Climate Action Plan[8].

Due to the importance of context when designing for resilience and the potential wide range of stressors to study, this study narrowed the focus to one region. The focus of the study is on the primary acute hazards and the impact of climate change for the Midwest. While the focus of the study is on the Midwest, many of the design strategy findings and analytic approaches in this study are applicable in other regions.

This study was further refined to examine resilient design at the scale of the building and site focusing on a baseline office building and hospital. Since buildings do not exist in isolation, this study's analysis takes into account the interaction between different systems and scales. For example, sustainable design strategies focusing on improved stormwater management not only impacts the site but has broader implications for the city sewage systems and for the climate by reducing the need for treatment and subsequent greenhouse gas emissions. To incorporate these interrelationships in the analysis, a set of 28 design strategies was selected to examine. From this information, a booklet – Resilience Design Booklet: A Framework to Quantify + Assess Resilience - of those design strategies was developed to begin to compare design strategies and communicate the benefits and costs of designing for resilience.

## 1.1 Framing Resilience

Since resilience is a malleable term with many different meanings and interpretations, the initial research stage focused on situating this study within those ongoing discussions. The definition of resilience influences the hazards that are designed for and the design strategies chosen. In relation to the built environment, there are three predominant approaches to resilience: ecological, engineering, and an emerging concept of evolutionary resilience. Each frame is discussed further below. However, resilience is increasingly being viewed as a combination of all of these. Resilience is designing for the acute hazards, chronic hazards, the interconnectivity between systems and scales, and the influence of climate change with a focus on the way these crises fundamentally change how we live.

Engineering resilience focuses on the stability and constancy within the system that ensures the protection of physical or human assets[9]. FEMA's disaster mitigation guidance[10], the Fortified for Safer Business Program[11] and the design of stronger buildings predominately focuses on this type of approach for mitigating risk. The issue with a sole focus on engineering resilience is that it results in catastrophic failure when it does fail and can disconnect the building from its context with unintended consequences. Hurricane Katrina is a well-known instance of catastrophic failure. While the city was protected during many smaller events, reliance on one system for protection and complete trust in it created the conditions where failure of the levee had massive consequences. The flooding in Europe in 2013 of the Danube River is one example of successful resilient design with unintended consequences further downstream. Flood mitigation measures installed in response to earlier floods in Dresden allowed this city to remain unscathed, however, it made the situation worse in other areas[12].

Ecological resilience is a systems-based approach focusing on "the magnitude of disturbance that can be absorbed before the system changes its structure[13]." It is based in preserving the functionality of the system as a whole. Design strategies for ecological resilience focus on those that build in adaptability, redundancy, and diversity into the system allowing for small failures while minimizing the chance of catastrophic failure[14]. Examples of these strategies can be seen in the USGBC Building Resiliency Taskforce[15], such as incorporating renewable energy supplies to mitigate the consequences of power outages to diversifying the energy supply chain. This approach to resilience heavily incorporates sustainable design strategies. It looks at the longer term and the relationships between different systems and scales from the building to the city.

Evolutionary resilience is a more recent approach. Unlike an engineering or ecological approach, evolutionary resilience questions the assumption that the previous behavior of a system is a good indicator of future behavior. This approach emphasizes that a system transforms when exposed to stressors and can fundamentally change the behavior of the system as a whole, requiring new ways to adapt to it[16]. Evolutionary resilience views climate change as an element that is introducing a number of new stressors into the system that will transform how we live. Programs on the West Coast such as San Francisco's 'Non-potable Water Program'[17] show how the continual stress of drought is creating fundamental changes in the system from its past behavior and encouraging a new approach to how water is managed, such as rainwater capture or even use of graywater. When in designing for greater resilience in a building different approaches might be needed, or a combination of them, in order to design for the key stressors.

Instead of focusing design strategies that only respond to one framing, this study focuses on design that thoughtfully responds to the risks and the context in which the building is located and integrates design strategies from each of these ways of framing resilience. The aim for resilient design is to "pursue buildings and communities that are shock resistant, healthy, adaptable, and regenerative through a combination of diversity, foresight, and the capacity for self-organization and learning[18]."

## 1.2 Methodology

The study was based on a literature review examining how resilience has been framed starting from C.S. Holling's seminal text to more recent approaches, such as the "City Resilience Framework[19]." This study also builds on related literature within the fields of sustainability and green design, disaster mitigation, and climate change to identify some of the key themes and issues for resilient building design in the Midwest.

The initial framework and assessment for resilience is based upon Bruneau's existing disaster mitigation framework, "Framework for Analytical Quantification of Disaster Resilience[20]." While Bruneau's framework provided a good base for the organization of the study, since it evaluated resilience through the lens of an acute disaster, it limits resilient design primarily to an engineering framework. To broaden the scope to the additional framings of resilience and incorporate the wider range of stressors into the study, three key additional issues were identified for the literature search. In addition to disaster mitigation and acute hazards, climate change, sustainability (indicators based on LEED), and the role of the building in the community were incorporated. Table 1 shows the framework.

Table 1: Adapted Resilience Framework and Assessment incorporating key issues of climate change, sustainability, and the role of the community.

| Building and Context | Resilience Assessment | Adaptation + Modification |
|---|---|---|
| Baseline Building<br>Risks<br>Acute Hazards<br>Chronic Hazards<br>Climate Change Impact | Cost Modeling<br>Capital Costs<br>Operational Costs<br>Acute Disaster Indicators<br>Failure Probability<br>Time to Recover<br>Consequences from failure<br>Sustainability Indicators<br>Energy + CO2 Emissions<br>Water<br>Air Quality, Resources<br>Health + Wellbeing<br>Community Role | Design Strategies<br>Benefits<br>Costs |

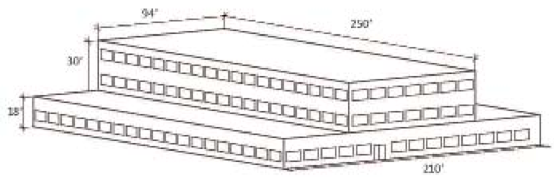
Since the scope of the research was narrowed to the Midwest, the study focuses on the key stressors of the region and a focus on acute and chronic hazards due to climate change. The National Climate Assessment was used to develop a list of the chronic hazards for the region. These include an increase in high temperatures and extreme heat days, changing seasonal precipitation patterns resulting in increased flooding and drought, and poorer air quality[21]. High winds, hail, and tornadoes were additional acute hazards incorporated into the study, as they are common stressors in the region.

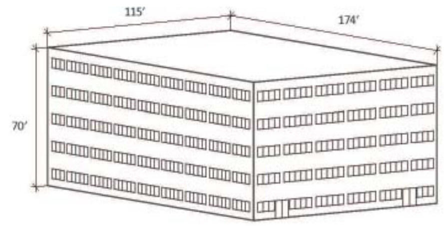
Further refinement in the scope was to focus on the building and site scale to simplify the potential number of design strategies that needed to be examined. A set of 28 design strategies, described in Table 2, mitigating the hazards for the building scale were developed from ReLi, a resilient design tool in development by Perkins+Will, in addition to guidelines such as LEED[22] and FEMA[23]. ReLi is a resource and leadership tool focusing on key criteria at both the community and building scale for resilience. These design strategies were then applied to two baseline test buildings – that of a hospital and office –to evaluate the costs and benefits. The hospital was selected due to its role in contributing to a community's resilience and its role as a critical facility during an acute hazard. Since the financial implications and needs of a hospital are different than the majority of buildings, analyzing only hospitals limits the applicability of the study. An office building was incorporated to broaden the study, as it contributes to the long-term resilience of a community. Resilience is not only about responding to the acute and chronic hazards; however, it is also about everyday functionality and how that functionality returns after an acute hazard.

Table 2: The investigated design strategies and the acute and chronic hazards they mitigate including general hazard preparedness.

| Design Strategy | Hazard | Description |
|---|---|---|
| Above 500 year Flood Plain | Flooding | Build above the 500yr flood plain, taking into account future projections due to climate change. |
| Backup Power (16 + 96 hrs) | Hazard Preparedness | Provision of a backup generator running on diesel or natural gas providing sufficient fuel for 16hrs (office) or 96hrs (hospital). |
| De-Couple Systems (DOAS) | Air Quality + $CO_2$ Emissions | De-couple the thermal conditioning of the building from ventilation systems installing a DOAS unit, ductwork and controls for ventilation. |
| Envelope Strengthening | Tornadoes, High Winds, Hail | Laminated glass window assemblies, strengthening roof systems to resist uplift, doors and windows designed to comply with wind testing loads. |
| Exterior Shading | Hazard Preparedness | Shading devices applied to the south and west sides of the building. |
| Form for Daylighting | Air Quality + $CO_2$ Emissions | Narrow floor plate designed for daylight with daylight sensors. |
| Graywater Treatment | Drought | Gray water treatment installed for use in bathrooms or as irrigation. |
| Green Roofs | High Temperatures | Extensive green roof. |
| Heat Recovery | Air Quality + $CO_2$ Emissions | Heat recovery ventilation system. |
| High Performance Envelope | Hazard Preparedness | High performance envelope: Wall R-value=25, Roof R-value= 50, Window R-value=4.5 |

| Design Strategy | Hazard | Description |
|---|---|---|
| Increased Ventilation | Air Quality + $CO_2$ Emissions | Increasing the breathing zone air ventilation rates to occupied spaces by 30% above the minimum ASHRAE rates. |
| Low Emitting VOC Materials | Air Quality + $CO_2$ Emissions | Use of materials with low or zero emitting VOC's. |
| Material Specification | Tornadoes, High Winds, Hail | Avoid specifying materials that perform poorly in high winds based on FEMA recommendations. |
| Passive Cooling | Hazard Preparedness | Shading, operable windows, and green roof. |
| Permeable or pervious Paving | Flooding | Change 50% of pavement to pervious pavement. |
| Raise Critical Equipment | Flooding | Raise the critical equipment and backup systems above the 500 yr flood mark. This study used a mechanical penthouse. |
| Rainwater Catchment | Drought | Addition of storage tanks and a circulation pump. |
| Reduce Soil Compaction | Flooding | This study used soil amendment to reduce compaction. |
| Reduce Water Use, Indoor | Drought | Use of low flow fixtures (Water Sense labeled in this study). |
| Reduce Water Use, Landscape | Drought | Reduce landscape water use by 50-100%. This study assumed the use of native plants, taking into account changes in climate ranges. |
| Renewable Energy | Air Quality + $CO_2$ Emissions | Renewable energy (using solar panels) that makes up 5% of the total building energy. |
| Safeguard Toxic Materials | Flooding | Ensure toxic materials are stored above the 500 year flood plain. |
| Sewage Backflow Valve | Flooding | Installation of a sewage backflow valve to prevent sewage from flowing into the building in flood prone areas. |
| Trees and Vegetation | High Temperatures | Increase of trees and vegetation on site by 10% reducing the site temperature. |
| Tornado Safe Room | Tornadoes, High Winds, Hail | Tornado safe room based on FEMA 361 added to each floor. |
| On-site Storage | Hazard Preparedness | On-site storage for 96hrs of essential food, supplies and materials in hospital above the 500 yr flood plain. |
| Operable Windows | Hazard Preparedness | Each window has an operable windowpane for passive cooling when the power is out. |
| Water and Power Outages | Hazard Preparedness | Ensure water is available and that toilets and sinks work when the power is out. This study added a storage tank to the roof to ensure sufficient water pressure. |




**Office**
Area: 100,050 GSF
Capital Cost: $22,877,000
Cost/GSF: $229/GSF
Glazing: 30%

**Acute care Hospital**
Area: 129,450 GSF
Capital Cost: $59,434,000
Cost/GSF: $459/GSF
Glazing: 30%
Beds: 50

Figure 1: Baseline buildings and initial costs.

Two different approaches were used to evaluate costs and benefits. For the costs, two generic baseline buildings were developed and are represented in Figure 1. With those baseline buildings, Mortenson Construction helped to evaluate an initial capital cost and the additional costs of each design strategy. The baseline building cost was based on five representative projects for each building type – for both the office and hospital. These representative projects were then averaged to develop a baseline building cost for each type. Figure 1 shows the cost for the two baseline buildings in addition to the parameters for the buildings.

The benefits were more difficult to determine and, instead of an exact quantification, are based on existing studies and research for the benefits of each strategy (in the Resilience Design Booklet, all the benefits and the relevant publications are stated). There were limitations within this approach, particularly in how to incorporate the benefits of an integrated design solution and how many of these strategies could result in savings in the capital costs, such as a reduction in mechanical system size.

## 2.0 FINDINGS

This section presents the key findings of the study, the primary issues for resilience in the Midwest and the potential costs and benefits of resilient design. This section also identifies potential areas for further research.

### 2.1 Resilience and the Issue of Climate Change

The Midwest will experience, and is already starting to feel the impact of climate change. Heat waves and downpours are becoming more frequent and snow and ice is arriving later and leaving earlier[24]. Depending on different emissions, climate change scenarios, and mitigation, this will influence the types and amount of adaptation strategies required in the future to respond to the increased risks. To avoid the worst consequences of climate change, the scientific evidence shows that emissions need to be reduced enough to keep temperatures from rising 2$^{o}$C (3.6$^{o}$F) above pre-industrial levels[25]. The amount and extremes of climate change risks can still be influenced by choices made today on addressing climate change, however, the time frame for influence is decreasing[26].

This study found that a number of design strategies implemented now influence both the adaptation and mitigation of the impact of climate change. Minnesota, Wisconsin, Iowa, and Michigan, for example, are either in the process or already have state adaptation plans for climate change. Sustainable design and passive design strategies in particular contribute to both adaptation and mitigation. Some of the strategies that adapt and mitigate climate change include: green roofs, exterior shading devices, high performance envelopes, and an increase in trees and vegetation on site. These strategies reduce the greenhouse gas emissions; however, they also ensure a level of thermal safety during acute hazards. This is especially relevant for hospitals as they are large consumers of energy in the building sector[27]. Recent disasters have raised concerns about the thermal safety during acute hazards, such as in Hurricane Katrina and extreme warming forcing evacuation[28].

There is also strong evidence of additional benefits such as improved health and productivity of building occupants[29].

## 2.2 Costs and Benefits of Resilient Design Strategies

Resilient strategies' initial capital costs are much easier to quantify than benefits (these estimates are approximate because this study did not have a specific site and was focusing on the regional scale). For the 28 design strategies, each of these could be quantified and the majority were less than one percent of the total capital cost of the buildings (for both the hospital and offices). The design strategies that had higher costs included the mechanical systems, such as heat recovery system, or tornado hardening. The benefits of an integrated design approach were difficult to quantify. Within capital costs, the reduction in mechanical system sizes that would result from a passive design approach were not reflected. An integrated design approach would influence the cost and reduce the capital costs associated with resilient design.

While the capital costs could be identified, the benefits presented more of a challenge. The literature is growing for the long-term benefits of design strategies, particularly for sustainable design. However, how those benefits are measured, who accrues the benefits, and the quantity of evidence varies by design strategy making it difficult to directly compare or communicate what potential benefits are for a project. For these reasons, the benefits were more loosely defined with the aim being to illustrate these complexities and at the same time begin to identify possible benefits, who benefits, incentives that might change the equation and the studies or research that information is based on. Figure 2 provides an example of one of the strategies – green roofs. The Resilience Design Booklet contains the findings for each of the 28 design strategies and this example is illustrative that for many of the design strategies, there are a number of potential benefits from acute hazard mitigation through to addressing chronic hazards; however, the quantification of the benefits depends on context, who benefits and the incorporation of a systems analysis instead of a narrow focus on the building. For

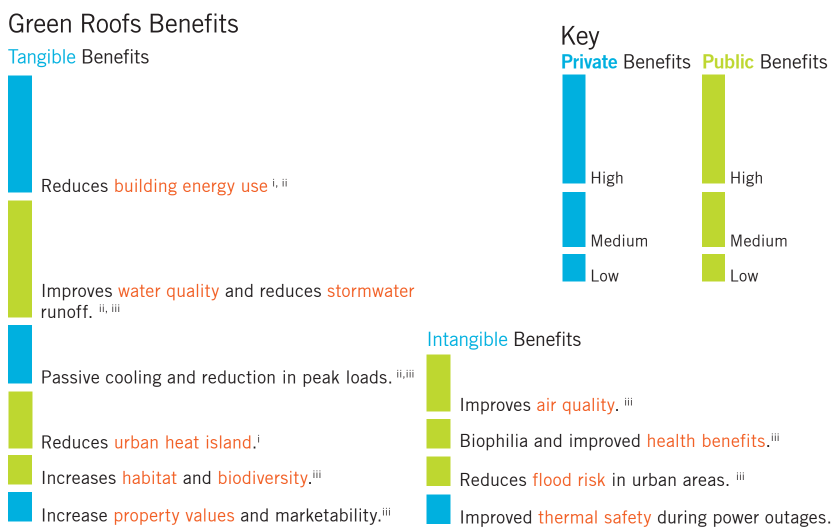



Figure 2: Example of the benefits of green roofs.

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all of the design strategies, the benefits referenced are findings from existing studies and literature.

Even though the research for many of the design strategies have only recently begun to identify all of the potential benefits, there were a number that have already shown to provide a return on investment. Many of these are based in sustainable design and include green roofs, trees, and reducing soil compaction in addition to passive design strategies, such as shading and high performance envelopes that reduce the energy use of the buildings. Other strategies, such as permeable or porous paving, have a strong and growing body of evidence for their benefits. However, further research is needed as there are a variety of materials or approaches for permeable paving that influence the financial equation with research showing that there is a shorter lifespan and higher maintenance required, depending on the types used. The Resilience Design Booklet begins to identify the existing research and potential benefits of resilient design.

## 2.3 Additional Costs of Resilient Design for a Project

As mentioned, the challenge with the breadth of the study meant that the costs and benefits of an integrated design approach were difficult to incorporate. This was particularly the case with the design strategies that would impact the mechanical systems. The potential reduction in the initial sizing of the mechanical systems, due to reduced load, was challenging to incorporate without an in-depth energy analysis to determine the load reduction. Design strategies that would influence it – and would help to reduce initial capital costs – include the green roof, building form, de-coupling systems, operable windows, and shading devices. The reduced capital cost from implementation of particular strategies was not incorporated.

With the 28 design strategies quantified – shown in Table 3 - this research then applied them to both the hospital and the office baseline building to see what the potential added costs were. As the study was based in the Midwest and not at a particular site, all of the strategies - except for graywater treatment for both buildings and rainwater collection for the hospital - were included in the added cost. For this study, graywater treatment was not included due to its costs and the Midwest context. While the Midwest will have a changing relationship to water and drought conditions, severe drought is not as key of a stressor as on the West Coast. Due to the cost of the system, using graywater makes more sense in areas experiencing severe drought. In addition,

Table 3: Additional costs of resilient design strategies for the office and hospital buildings.

| Design Strategy | Office: Design Strategy Added Cost | Hospital: Design Strategy Added Cost |
|---|---|---|
| Above 500 year Flood Plain | $0 | $0 |
| Backup Power (16 + 96 hours) | $10,000 | $260,000 |
| De-Couple Systems (DOAS) | $337,500 | $685,000 |
| Envelope Strengthening | $1,203,000 | $1,320,000 |
| Exterior Shading | $170,600 | $100,000 |
| Form for Daylighting | $262,500 | $489,000 |
| Graywater Treatment | $275,000 (not included) | Not included |
| Green Roofs | $200,000 | $510,000 |
| Heat Recovery | $240,000 | $800,000 |
| High Performance Envelope | $285,000 | $394,000 |
| Increased Ventilation | $162,500 | $292,500 |
| Low Emitting VOC Materials | $0 | $0 |
| Material Specification | $0 | $0 |

| Design Strategy | Office: Design Strategy Added Cost | Hospital: Design Strategy Added Cost |
|---|---|---|
| Passive Cooling | Costs included in specific design strategies (Exterior Shading, Green Roofs, Shading, Operable Windows, Trees and Vegetation) | Costs included in specific design strategies (Exterior Shading, Green Roofs, Shading, Operable Windows, Trees and Vegetation) |
| Pervious Paving and Reduced Soil Compaction | $176,000 | $578,000 |
| Raise Critical Equipment | $220,000 | $400,000 |
| Rainwater Catchment | $176,500 | Not included. |
| Reduce Water Use, Indoor | $25,000 | $424,000 |
| Reduce Water Use, Landscape | + $70,025 (operational savings) | + $125,000 (operational savings) |
| Renewable Energy | $175,000 | $1,186,500 |
| Safeguard Toxic Materials | $0 | $0 |
| Sewage Backflow Valve | $5,000 | $5,000 |
| Trees and Vegetation | $140,000 | $249,500 |
| Tornado Safe Room | $461,500 | $1,075,500 |
| On-site Storage | $0 | $0 |
| Operable Windows | $11,000 | $18,000 |
| Water and Power Outages | $150,000 | $450,000 |

rainwater was not included for a hospital due to varying codes and differing views on using rainwater within a hospital setting.

Additionally, on projects and with an integrated design process, not all the design strategies would be applied. Instead, the design strategies selected would be those that respond to the key risks and stressors for that particular site. There would also be an interplay between many of the strategies. To manage stormwater, for instance, a combination of strategies would probably be used and those selected would be highly dependent on context and site. In urban areas with limited space, green roofs would be a more efficient use of space to manage stormwater than wetlands. Context is key to the strategies selected and employed.

Assessing the potential added costs for a project - with the design strategies in Table 3 applied to the baseline buildings - this study found the added cost was between 15-19 percent for the hospital and office buildings, with the hospital being on the lower end of the range. However, these costs are on the high side due to the design of the study; particularly the lack of an integrated design approach and, as in many projects, a mixture instead of all the design strategies would be applied. Depending on the context, scale, and program of the building – if it is a critical facility or an office building - these will influence the costs and also design strategies selected when designing for improved resilience.

## 2.4 Related Evidence for Resilient Design

Other projects that illustrate the potential costs of resilient design are the rebuild of Mercy Hospital in Joplin and the “Targeting 100!” Study by the University of Washington. In the case of Mercy Hospital in Joplin, it was hit by an EF-5 tornado in 2011 where six patients died in the hospital. The new hospital was designed to be ‘virtually tornado proof’ with safe zones for each floor, laminated glass designed for EF-3 tornadoes, and in critical patient areas, hurricane rated glass, along with two protected backup generators, two independent electrical feeds, and water supplies[30]. The design of the hospital in Joplin used more extensive tornado hardening than this study proposed. The additional cost for the tornado hardening was approximately 2-3 percent of the total project cost. These measures mitigate the future consequences from a tornado and the potential costs from a tornado, as was illustrated in Joplin, range from loss of life, the loss of the building through to renting temporary facilities, staff retention, and the more intangible cost to reputation. Evaluating the full cost from a disaster is another area for additional research incorporating not only the physical asset loss, but also the costs until recovery and the intangible costs.

While Mercy Hospital is designed for resilience to acute disasters, "Targeting 100!" is a study by the University of Washington's Integrated Design Lab providing a roadmap for hospitals to achieve the 2030 Challenge with a 60 percent energy reduction, with the strategies tested in each region of the United States. Energy and greenhouse gas emission reductions are a key element in mitigating climate change and building for resilience. The "Targeting 100!" study used similar design strategies as this research; however, they used an integrated design approach early on in the process and in-depth energy modeling. Some of the design strategies to reduce energy use included: high performance envelope, 30 percent glazing area, dynamic shading, form for daylighting, and displacement ventilation with radiant panels. "Targeting 100!" found that a 60 percent reduction in energy use was possible with a three percent added cost and a nine percent return on investment[31]. Both of these examples and the difference with this study illustrate the need for further research examining the potential costs of designing for resilience – particularly on real projects.

## 3.0 CONCLUSION

This study indicates that there is strong evidence that resilient design offers many benefits, both tangible and intangible. The Resilience Design Booklet describes the evidence for the benefits of design strategies; however, this study has not quantified a summary figure for those benefits. This is due to the differing units of measurement used for assessing the benefits of design strategies that range from cost and operational savings through to intangibles, such as productivity or improved health. Providing a summary figure for the benefits - given the wide range and different quantifying techniques - would require a more narrowly defined site and context.

While there are benefits and designing for resilience mitigates risks, resilience is still an elusive topic and is an area where further case studies and research is needed. Sustainable design and passive design strategies offer the greatest potential for benefits from energy savings, improved health, and productivity of building occupants. The impact of these changes can be large if these strategies are adopted on a broader scale, such as Chicago's Green Roof Initiative, influencing flood risk through to stormwater systems and improved health and air quality – all issues that the Midwest will be experiencing due to climate change. While this research focused on the building scale, the analysis of the benefits of the design strategies highlighted the interrelationships between different systems and scales. The building is part of larger systems and is intimately connected to them. A building is only as resilient as the larger systems to which it is connected.

Current trends will also create change within the cost and benefit equation. Energy efficiency improvements in ASHRAE 90.1, its impacts on LEED and state codes, in addition to the declining costs of solar and renewable energy, will transform the future cost of energy and renewable systems. Through reducing energy use in a building, this can minimize exposure to changing energy costs, while mitigating the costs if an acute hazard occurs with improved thermal safety. Resilient design can offer operational and long-term savings while also building in the ability to respond to an acute hazard.

Further research will help to inform and clarify these issues; however, an important question is raised: what are the risks from waiting to adapt to and mitigate climate change? There are significant economic risks from climate change[32] and there will be additional disruptions to systems that we rely on, such as energy, food, and water. Once global warming and temperatures rise above 2°C, the opportunity to mitigate climate change will decrease with more extreme risks to design for. The key finding of this research is that the costs of designing for resilience on a project can be quantified; however, further research is needed to measure resilience and the potential costs or benefits – short-term and long-term – on a project. As these issues are based on context, this cost will likely vary based on the key risks for a specific site. Meanwhile, the risks from climate change are becoming clearer, with the IPCC report and Risky Business, and the research on potential benefits of resilient design strategies is growing with many strategies already offering a return on investment.

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