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The Sustainable Prescription: Benefits of Green Roof Implementation for Urban Hospitals

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If worldwide healthcare was a country, it would be the fifth largest emitter of greenhouse gases on the planet. The increase in global temperatures, combined with the negative impacts of urbanization, has made it more important than ever to introduce green spaces where possible. With climate change worsening, human health, both physically and mentally is on decline, making the effects of climate change especially pressing to the stability of healthcare systems. In order to mitigate the lasting impacts of climate change on healthcare facilities, a holistic solution is needed. Access to green space in hospitals has been shown to reduce emotional distress, improve mental health, increase socialization and community connection, increase physical activity, decrease cardiovascular and respiratory diseases, decrease pain management needs and hospital stay lengths and increase both patients' and staffs' overall satisfaction at the facility. Beyond benefiting those interacting with the hospital, green roofs have the ability to reduce the urban heat island effect, improve stormwater mitigation, increase biodiversity, and absorb toxins and pollutants through air filtration. Additionally, green roofs can offer lower maintenance costs and higher energy savings than traditional roofs, and improve patient satisfaction, which can result in future funding opportunities. However, the upfront and upkeep costs of installing a green roof can vary and must be considered before implementation. In this review, we explore the symbiotic relationship between urban green roofs and hospital/patient wellness through the lens of sustainability, which includes environmental, societal, and economic impacts. We review scientific journal articles investigating benefits of green space and green roofs and highlight examples of green roofs on hospitals in the United States; together, these approaches display the environmental, societal, and economic benefits of green roofs installed on healthcare facilities. This review offers insight to hospitals, decision makers, and government systems on the importance of green roofs in urban areas and how these infrastructures can support the economic growth of the institute. Using our framework, decision makers and planners for urban hospitals can evaluate how the addition of green roofs to their healthcare facilities can contribute to increased environmental resiliency, community health, and patient satisfaction.

Keywords: green roof, green infrastructure, urbanization, urban hospitals, sustainability, resilience (environmental)

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INTRODUCTION

During the summer of 2021, Earth experienced the hottest month on record (NOAA Research News, 2021). Extreme weather events, exacerbated by climate change, resulted in an estimated $210 billion in global damages in 2020 (Munich, 2021). The atmospheric carbon dioxide measured at NOAA's Mauna Loa Atmospheric Baseline Observatory peaked at just under 420 parts per million in May 2021, the highest recorded measurement (NOAA Research News, 2021). Each year ∼12,000 premature deaths occur due to heat exposure, which is projected to rise to between 50,000 to 110,000 premature deaths over the next century based on moderate and high warming scenarios respectively (Shindell et al., 2020). Many of these climate change related events, and their subsequent impacts, are made worse by reductions in green spaces, specifically in urban areas (Kingsley and, 2019). By 2050, global city populations are estimated to grow by ∼12% or "2.4 billion people" (Toli and Murtagh, 2020). As urban centers accommodate increased population growth, they increase their built infrastructure, which reduces green space, resulting in the limiting of ecosystem services, including climate mitigation (Coutts and Hahn, 2015).

Ecosystem services contribute to the longevity and well fare of humanity by providing food and water, regulating climate and pollutants, supporting shelter and biodiversity, and creating cultural variations, aesthetic values, and spiritual enrichment (Coutts and Hahn, 2015; Aerts et al., 2018). In this paper, we will be focusing on services such as stormwater mitigation, air filtration, carbon uptake, cooling through evapotranspiration, food, and intellectual and spiritual prosperity, and exploring them through the lens of sustainability (Costanza et al., 2014; Coutts and Hahn, 2015). The valuation of these services is based on the non-privatized contribution to human well being. For the purpose of this study, sustainability is defined by the environmental, social, and economic aspects that ensure security for current and future generations, where each pillar mutually benefits the other (The World Commission on Environment Development., 1987; Kuhlman and Farrington, 2010; Costanza et al., 2014; Sharafatmandrad and Mashizi, 2021). These three commonalities are recognized and interchangeably referred to as the 'three pillars of sustainability." Ecosystem services are an integral part of the three pillars of sustainability. Purposeful additions of green infrastructure can be an important part of improving sustainability and addressing the reduction of ecosystem services caused by climate change.

Green infrastructures, including "wetland detention basins, roadside bioswales, green walls, and green roofs" are human designed natural spaces that mimic aspects of a region's native environment with the goal of reintroducing ecosystem services to the local community in support of sustainable development (Coutts and Hahn, 2015; Filazzola et al., 2019). This paper focuses on the urban development of green roofs, a type of green infrastructure designed to be an extension of an existing or newly constructed roof that offers an expansion of a city's finite amount of available ground-level green surfaces. Green roofs are separated into two categories, intensive, and extensive. The distinction between the two is determined by the depth of the growing medium and the species of vegetation that can be supported within that growing medium (Rahman and Ahmad, 2012; Sadeghian, 2017; Alosio et al., 2019). Extensive roofs are shallow and support grasses and small plants requiring minimal upkeep while intensive roofs are a more complex structure with greater soil depths, a permanent irrigation system to support larger plant species, and a more diverse ecosystem (Benedict and McMahon, 2002; Rahman and Ahmad, 2012; Purvis et al., 2019). Mimicking the local ecological system through man-made green infrastructures can accommodate the loss of natural habitats in urban areas (Coutts and Hahn, 2015; Alosio et al., 2019; Knapp et al., 2019).

When considering potential urban locations for green roofs, healthcare buildings provide a promising opportunity to lead by example in sustainable initiatives (Eckelman and Sherman, 2016). Although hospitals are responsible for the health and safety of the public, in the United States, following food production, hospitals are the "second-most energy-intensive commercial buildings" (Eckelman and Sherman, 2016). The significant emissions from hospitals increase the risk of climate change related health issues and contributes to the general degradation of the environment caused by climate change (Costanza et al., 2014; Eckelman and Sherman, 2016; Toli and Murtagh, 2020). Urban hospitals provide ideal space for supporting green roofs because of: the ability for hospitals to mitigate environmental concerns affecting public health through ecosystem services provided by the green roofs; the hospitals' goals to improve the health and well being of the community; and the relatively high proportion that have large, flat, unoccupied roof space that is commonly unutilized (Ulrich, 2002; Coutts and Hahn, 2015; Feng and Hewage, 2018).

Health and well being, as we define them in this paper, refers to the physical, mental, and emotional needs that must be met to achieve overall holistic wellness for an individual (Seymour, 2016; Franco et al., 2017). Exposure to green space is an overlooked necessity in achieving comprehensive well being that has been utilized by several ancient civilizations who understood the mental and physical healing benefits of interacting with the natural world (Ulrich, 2002; Pouya and Demirel, 2015; Sandifer et al., 2015; Xue et al., 2019). The use of nature as a tool for healing, also known as horticulture therapy, has been found in early records of Ancient Egyptian physicians who prescribed therapeutic walks through healing gardens as an alternative form of medication to aid patients suffering from mental disturbances (Oh et al., 2018). Similarly, during the Middle Ages, enclosed gardens, or cloister gardens became a popular architectural design in European monastic infirmaries "to bring pleasant, soothing distractions to the ill" (Ulrich, 2002; Pouya and Demirel, 2015; Franco et al., 2017). As the bubonic plague progressed during the Middle Ages, monastic infirmaries were no longer able to care for the astronomical number of ill and dying patients, limiting the therapeutic use of nature as medicine (Marcus and Barnes, 1999). This began the rise of an institutionalized healthcare system as the need for government involvement and infection control developed in urban regions with higher population density. In the 1900s, hospitals aimed to increase efficiency by institutionalizing health care that, over the last 100 years, adversely evolved into a system that is perceived

to be "unacceptably stressful and unsuited to the emotional needs of patients, their families, and even healthcare staff," really treating the ill (i.e., "sick-care") rather than promoting health (Ulrich, 2002; Fries, 2020). Integrating green space in modern medicine has become increasingly prevalent in navigating the negative mental and physical effects of urbanization and the lack of exposure to green space in a hospital setting to support healing (Coutts and Hahn, 2015; Warber et al., 2015).

The addition of green roofs on hospitals may also help to improve patient satisfaction scores. In the United States, the Patient Protection and Affordable Care Act (PPACA) requires mandatory patient satisfaction surveys, including the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS), which are performed to measure the quality of patient satisfaction based on patient care and experience (Healthcare Information Management Systems Society, 2017; Presson et al., 2017). Scores from these surveys are available to the public through online forums where prospective patients and employees can create their own opinions of the business based on information shared by previous patients (Zusman, 2012; Presson et al., 2017). Decisions for allocation of funding to hospitals in the United States rely heavily on patient satisfaction scores (Zusman, 2012; Presson et al., 2017). In the US, health care facilities are funded through donors, insurance companies, and grants depending on the for-profit or nonprofit status of the facility; public hospitals are owned and operated by the government and use funds collected by taxpayers (Laschober and Vertress, 1995; Becker's Hospital Review, 2021). In addition to the potential funding benefits provided by green roofs, green roofs can also provide direct economic benefits to hospitals, such as increased energy efficiency, which could potentially overcome the initial costs of the green roof.

In this paper, we review journal articles and real-life examples to investigate how green roofs that are built on hospitals are able to address the three pillars of sustainability through the following questions: (i) What are the potential environmental benefits associated with a green roof built on an urban hospital?; (ii) How could the stakeholders utilizing and surrounding the healthcare facility, including the patients, visitors, employees, and community members, benefit from the addition of a green roof?; and (iii) Will the addition of a green roof be economically beneficial to the hospital system (**Figure 1**)? An additional goal of the paper is to offer insight to hospitals, decision makers, and government systems on the opportunity of green roofs in urban areas and how these infrastructures can have environmental, societal, and especially, economic gains to the organization.

METHODS

Research for this study examined the impact that green roofs have on their surroundings through peer-reviewed literature and practical real-life examples of green roofs on urban hospitals. The inclusion of both research articles and examples of green roofs on hospitals in this review allowed us to investigate how green roofs and hospitals are viewed in both an academic and non-academic setting and see what facets of sustainability are supported by each of the research articles and real examples. The use of the different information sources allows for a more complete picture of the sustainability benefits of green roofs and hospitals.

Databases utilized in our research included ResearchGate, MDPI, Science Direct, JSTOR, Scopus, and National Center for Biotechnology Information. Google Scholar was also used as a search engine to identify relevant articles. In order for a journal article to be considered for this review article, the article must have been written in English and peer-reviewed. Several books, considered to be of great importance to this topic area, such as that by Marcus and Sachs (2013), were also included in our review. Broad searches for this research included keywords of "urban" and "green roofs," "nature" and "healthcare," "three pillars of sustainability," and "urban climate change." These search words were used in combination with each other, most commonly "green roofs" and "urban" in conjunction with the other search words. These searches provided some relevant information but more importantly led to the refinement of search words. Additional searches included keywords of "green roofs" paired with "health benefits," "economic benefits," and/or "environmental benefits." Because of the limited scientific research on green roofs on urban hospitals, further searches also included keywords such as "human connection," "biodiversity" and "human health," "stormwater management," "air pollution," "physical health benefits" in conjunction with "green roofs" and "green spaces." This wider lens allowed us to investigate and consider how the benefits accrued to green spaces and green roofs in one area might be applied and expanded to green roofs located on urban hospitals. Additionally, we examined literature that cited other key literature, such as that by Ulrich, to investigate how this research has evolved in recent years. In excess of 30,000 articles were located based on this methodology. In order to select articles for this review, the top 10–20 articles from each search were skimmed to determine which articles were relevant. Based on this approach, ∼100 articles were used in this review. The selection of these articles is based on a combination of the following: relevancy to the topics of interest, importance to the field of study, comprehensiveness of the paper, and date of publication. While there are many journal articles included in this review, there was very limited scientific research specifically related to hospitals with green roofs in the United States.

In addition to scholarly articles, we included five examples of green roofs on hospitals in our review. Since there was minimal scientific research found specifically regarding hospital green roofs, we researched hospital web pages, news articles, and websites of landscape architects that aided in the construction and design of the green roofs to understand how green roofs on the hospitals are portrayed in publicly available information. We chose five urban hospitals in the United States to highlight in this study as examples of the benefits of green roof implementation on hospitals because of their commitment to sustainable practices: Fletcher Allen Hospital of University of Vermont Medical Center, Burlington, Vermont; Rady Children's Hospital, San Diego, California; Sharp Memorial Hospital, San Diego, California; Metro Health University of Michigan Health, Wyoming, Michigan; John Theurer Cancer Center at the Hackensack University Medical Center (HUMC), Hackensack,

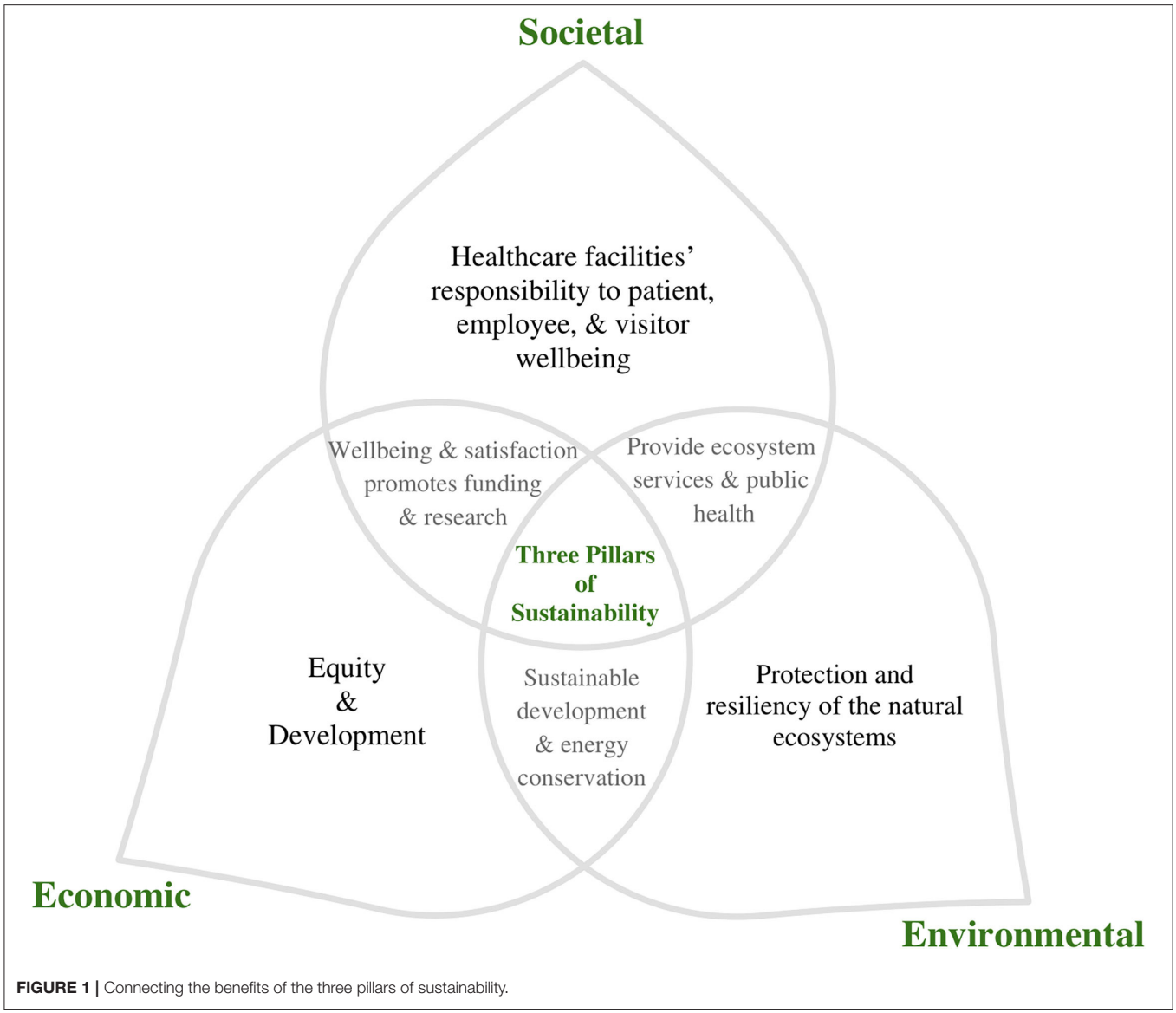

FIGURE 1 | Connecting the benefits of the three pillars of sustainability.

New Jersey (**Table 1**). Criteria used to select the diverse hospitals in the United States that we report on included: a range of climate zones in which the hospitals are situated; representation of diverse urban geographic locations; visible or physical accessibility by patients, family members, and employees to the green space; and the range of benefits the hospital green roofs provide to the environment, the clients, and the business.

ENVIRONMENTAL BENEFITS OF GREEN ROOFS ON URBAN HOSPITALS

The integration of green roofs and ecosystems as part of green infrastructure is a purposeful design mechanism that is implemented in urban communities. These designed green spaces help cities to mitigate the negative environmental impacts that result from increasing urbanization and growing built environments, which are depauperate in biodiversity and ecosystem services (United States Environmental Protection Agency, 2015; Knapp et al., 2019). We observed that leaders in sustainable initiatives who have constructed green roofs, including some examples from the healthcare industry, benefit the environment by minimizing the urban heat island effect (UHI), improving stormwater mitigation, increasing native biodiversity, and reducing greenhouse gas emissions and air pollution (**Figure 2**).

Increasing population densities in urban centers result in greater energy use and higher total greenhouse gas emissions, which contribute to the UHI effect (Mutani and Todeschi, 2020). UHIs create microclimates with temperatures increased by 2–5%, and these increases could be mitigated through the addition of vegetation (Castleton et al., 2019; Mutani and Todeschi, 2020).

TABLE 1 | Hospital green roof descriptions.

Hospital	Location	Installation year	Goals	Project description	Square footage (ft^2)	Category	Accessibility	Acknowledgments	Sources
Fletcher Allen Hospital	Burlington, Vermont	2010	Develop plans to include "sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality" Follow LEED Certification	Green roof and healing garden built on top of Radiology Oncology Center	18,000	Intensive	Accessible	Leading hospital in the US through their sustainability and green initiatives Received the Practice Greenhealth, Top 25 Environmental Excellence award in 2019 for their commitment to a greener hospital	The University of Vermont Medical Center (2020) Greenroofs.com (2021a)
Hackensack University Medical Center (HUMC)	Hackensack, New Jersey	2011	Create a stress-free and educational environment for patients and families	Roof garden built on top of HUMC's John Theurer Cancer Center, providing "picnicking space, a grassy area, and raised beds for growing food"	7,500	Intensive	Accessible	Awarded, multiple years running, "Top 25 Environmental Excellence Award"	Greenroofs.com (2021b)
Metro Health University of Michigan Health	Wyoming, Michigan	2007	LEED Certification	Living roof built on top of the main hospital	48,500	Extensive	Accessible	Second largest green roof in Michigan	Greenroofs.com (2021c)
Rady Children's Hospital	San Diego, California	1998 and 1999	Expand the green initiatives of the hospital in order to meet the growing demand and higher satisfaction with the original healing garden	First built the Leichtag Family Healing Garden then a year later built Carley's Magical Gardens because of the benefits experienced from the first green roof	N/A	Extensive	Accessible	Interactive space including mazes, sculptures, and picnic tables	Rady Children's Hospital-San Diego (2021)
Sharp Memorial Hospital	San Diego, California	2010	Transform the "bleak" rooftop into a place of healing	Healing gardens built on top of the emergency room because of the hospital's "All Ways Green" Initiative	5,000	Extensive	Non-accessible	Named "Most Beautiful Hospital in the World" (HealthExecNews.com) with aid from their "eco-friendliness" and "therapeutic environment"	Greenroofs.com (2021e) NBC 7 San Diego, 2021

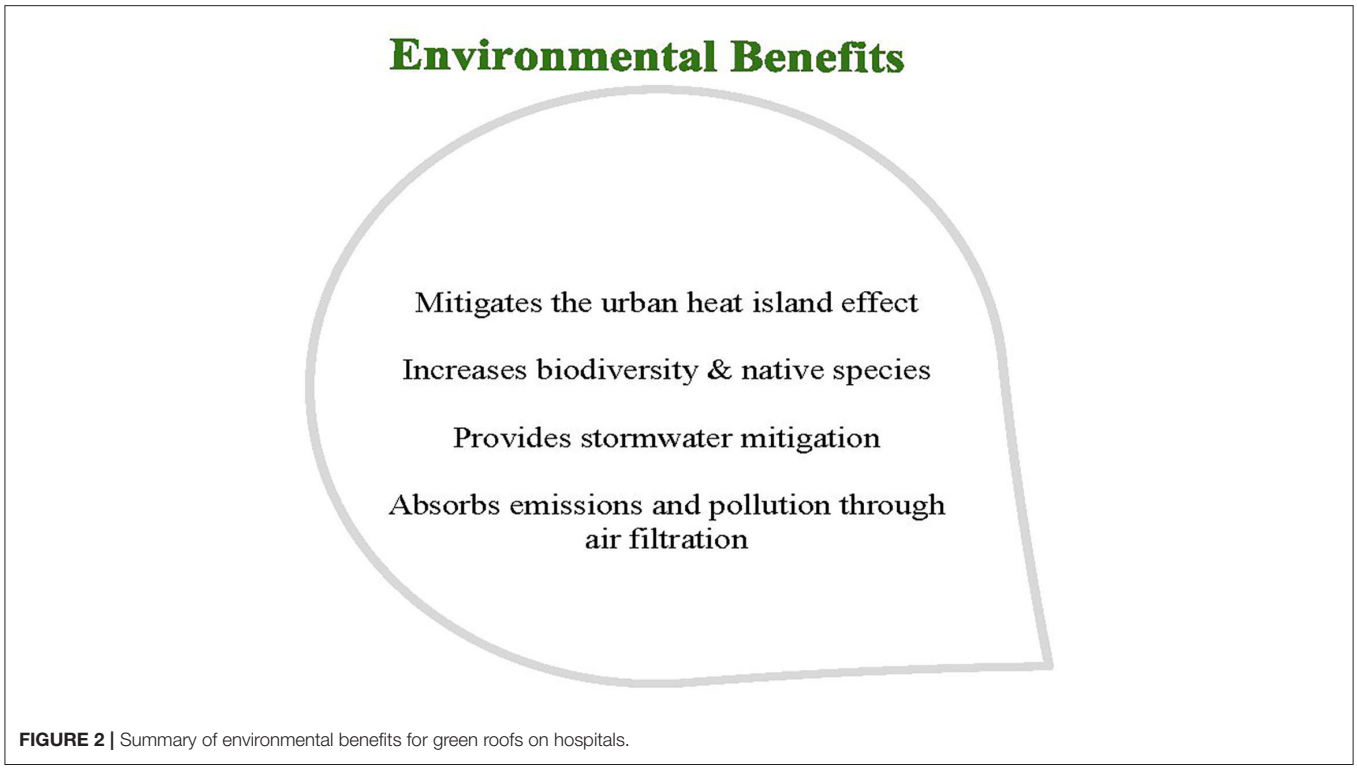

FIGURE 2 | Summary of environmental benefits for green roofs on hospitals.

Traditional roofs reach temperatures between 149°F-194°F (60–95°C) by absorbing heat from the sun during the day and quickly releasing the stored energy at night. The built infrastructure in cities adds surfaces that can absorb heat and release it at night, increasing atmospheric temperatures contributing to the UHI effect (Rakhshandehroo et al., 2015). Green roofs in urban areas, on the other hand, have been documented to reduce a roof's surface temperature as well as the rate of solar radiation transferred, in addition to cooling the air through evapotranspiration. Collectively, these actions reduce the UHI effect (Rakhshandehroo et al., 2015; Bevilacqua et al., 2017; Feng and Hewage, 2018; Cai et al., 2019). The naturally occurring insulating properties of plants and vegetation create a barrier between the sun and the building, limiting the amount of solar radiation that is absorbed and released as wasted energy (Shafique et al., 2018). The rate of solar radiation transferred onto building roofs with green roofs ranges from 6-30% in the summer and 10–80% in the winter based on the density and type of plants and the amount of evapotranspiration occurring (Rakhshandehroo et al., 2015; Feng and Hewage, 2018). The reduced solar radiation transferred, in addition to the cooling effects from evapotranspiration, result in green roofs having surface temperatures less than half that of a traditional roof (Bevilacqua et al., 2017). As a result, the ambient air within a building's microclimate on the roof is between 2.2 and 2.8 times lower in temperature, offsetting a portion of the UHI contribution of the building (Bevilacqua et al., 2017). Metro Health University has one of the largest square footage of green roofs mentioned in this paper with "108,000 flowering plants" made up of 5 different species of sedum, covering 48,500 ft^2 (4,500 m^2) of the roof (Greenroofs.com, 2021c). Metro Health's large, vegetated roof area can combat UHI effect by insulating the hospital and cooling the surrounding air through evapotranspiration (Shafique et al., 2018). UVM's Fletcher Allen Hospital also cites a reduction in the UHI effect as a key benefit from their green roof (Greenroofs.com, 2021a). They constructed their green roof on what was previously a rooftop parking lot, which traditionally absorbs 95% of solar radiation, can reach temperatures 50°C higher than air temperatures, and is acknowledged as a major contributor to the UHI effect (H. Keith Wagner Partnership, 2011; Aletba et al., 2021).

In addition to the UHI effect, urban sprawl has also resulted in increased impervious surfaces and depletion of native plant species, causing a reduction in floodwater mitigation (Benedict and McMahon, 2002; Coutts and Hahn, 2015). The reduced potential of urban areas to effectively filter and absorb stormwater has been exacerbated by increased frequency of super storms because of climate change, resulting in greater flooding in urban areas (Brenneisen, 2006; Shafique et al., 2018; Castleton et al., 2019; Knapp et al., 2019; Mutani and Todeschi, 2020). Roofs account for 40–50% of the impervious gray space in cities (Shafique et al., 2018). By mimicking the natural hydrological cycle, extensive green roofs can retain 50% to 80% of a property's average rainfall contributing to greater stormwater management and reduce the risk of flash floods (Shafique et al., 2018; Knapp et al., 2019). John Theurer Cancer Center's green roof has recorded environmental success associated with the installation of their green roof, mainly through stormwater

retention. The "drought-tolerant GreenGrid green roof modules" used in the design of the green roof have been reported to retain "90% of summertime precipitation and 40% of wintertime precipitation" contributing to greater stormwater management and reducing the risk of flash floods (Knapp et al., 2019; Greenroofs.com, 2021b). Robert VanRees, the director of facility and support services for Metro Health Hospital, shared that by holding up to three inches of rain at any given time, their green roof has played a major role in allowing them to be a "zero discharge site," "none of [their] stormwater leaves [their] facility" (Dewey, 2014).

Along with stormwater mitigation, green roofs can benefit efforts to maintain and conserve biodiversity by serving as a reservoir, propagation, and dispersal site for native plants and animals. Cumulative effects of human activities in urban centers have wiped away native ecosystems causing a loss of biodiversity and indigenous plants, animals, insects, and microorganisms that each play an important role in supporting a resilient ecosystem (Coutts and Hahn, 2015; Partridge and Clark, 2018). Green roofs have been identified as key microhabitats for maintaining populations of species native to an area and supporting biodiversity (Brenneisen, 2006; Partridge and Clark, 2018; **Figure 2**). The Rhybank building in Basel, Switzerland recorded its green roof to be home to "79 beetle species and 40 spider species," of those insects, 13 beetle and seven spider species were classified as endangered (Brenneisen, 2006). A similar study examining the bird and arthropod species on green roofs in New York City found 41 species of birds on green roofs compared to the 14 found on conventional roofs (Partridge and Clark, 2018). These numbers are largely because of the increased arthropod populations that thrive on green roofs habitats over conventional roofing (Partridge and Clark, 2018; Partridge et al., 2020). The metropolitan area of Sydney, Australia reported that green roofs inhabited four times the avian population, over seven times the arthropod population, and twice the gastropod population of a conventional roof (Wooster et al., 2022). Green roofs also attracted locally rare species such as blue banded bees and metallic shield bugs that were never found on traditional roofs. The environmental benefit highlighted in these research articles was a focus during the design of Fletcher Allen Hospital's green roof. The hospital's green roof is designed to mimic the natural landscapes of Vermont by including species native to the area in support of local biodiversity (Brenneisen, 2006; Partridge and Clark, 2018; Greenroofs.com, 2021a). Architects with Cannon Design followed patterns found in Vermont's local "farm fields, meadows and villages" to aid in supporting natural habitats and "responsible site development" (Alosio et al., 2019; Greenroofs.com, 2021a). Increasing conservation efforts through green roofs offers alternative habitats to native species (Partridge and Clark, 2018; Partridge et al., 2020).

In addition to the environmental threats posed by urbanization, healthcare systems themselves contribute to climate change through their greenhouse gas emissions, such as those produced from energy consumption, product manufacturing, and transportation. Healthcare facilities worldwide are responsible for about 4.4% of all global greenhouse gas emissions; if worldwide healthcare was a country, it would be the "fifth largest emitter" of greenhouse gases on the planet (Karliner et al., 2019). As urban sprawl increases, air quality will decrease, negatively affecting the health and safety of the surrounding community, patients, and workers (Coutts and Hahn, 2015; Mutani and Todeschi, 2020). The issues created by pollution, including those emitted by healthcare facilities, are exacerbated by the altered air flow and circulation in cities, caused in large part by the way in which buildings are spatially organized in cities (Hayati and Sayadi, 2012). Green roofs constructed on urban buildings sequester emissions and can help offset their effects in populous areas. A study conducted in Chicago, Illinois, USA quantified the air pollutants removed by green roofs around the city and determined that each hectare of green roof, on average, removes 85 kg of pollutants each year (Yang et al., 2008). These pollutants are ∼52% ozone, 27% nitrous oxide, 14% particulate matter (PM_{10}), and 7% sulfur dioxide. Intensive green roofs are more successful at filtering pollutants than extensive green roofs, most likely because of the plants that intensive green roofs can support vs. extensive green roofs. Other studies have also shown that certain plant species are more successful at removing certain pollutants (Gourdji, 2018; Seyedabadi et al., 2021). For example, pine species planted on green roofs were found to be good candidates for removing particulate matter in Canada and a study in Mashhad, Iran that investigated over fifty different plant species on green roofs found that *Frankenia thymifolia* (sea heath) absorbed 2.07 kg/m of carbon dioxide through photosynthesis, more than 14 times that of another species, *Sedum acre* (gold moss stonecrop), included in the study (Gourdji, 2018; Seyedabadi et al., 2021). The best plant species to grow on urban hospital green roofs will depend on the climate of the hospital's location and may be a future area of interest and study as hospitals consider which plants will most align with the goals of their green roof.

Metro Health University of Michigan Health utilized six different types of drought resistant plants for the design of the green roof to support the surrounding community by "improving air quality, providing increased insulation, minimizing storm water runoff and reducing peak temperatures" (University of Michigan Health-West, 2021). In 2009, Sharp Memorial began the All Ways Green initiative striving to implement strategies to conserve energy and minimize waste to lower the hospital's environmental impact (Center for Sustainable Energy, 2021; Sharp HealthCare., 2021). As part of this initiative, the healing garden was built on top of the emergency room in 2010 to provide environmental benefits including stormwater mitigation, biodiversity enhancement, and filtration of air, water, and noise pollution (Greenroofs.com, 2021e). Hospital green roofs in urban locations have shown positive environmental outcomes including reducing the urban heat island effect, improved stormwater mitigation, increased biodiversity through natural habitat restoration, and absorption of toxins and pollutants through air filtration (Brenneisen, 2006; Yang et al., 2008; Coutts and Hahn, 2015; Bevilacqua et al., 2017; Partridge and Clark, 2018; Shafique et al., 2018; Grunewald et al., 2019; Knapp et al., 2019; **Figure 2**).

SOCIETAL BENEFITS OF GREEN ROOFS ON URBAN HOSPITALS

Biophilia is the theory that nature plays a necessary role in a person's well being because of our ancestors' connection to nature and reliance on it for survival (Capaldi et al., 2015; Xue et al., 2019). Aspects of nature that trigger the five senses, sound, sight, smell, taste, and touch, are processed through the unconscious mind activating a sense of peace and belonging (Jiang, 2014; Franco et al., 2017). Concrete, smoke, mechanical sounds, and other human-made pollutants associated with the rise of industrialization and urbanization negatively alter a person's overall health by limiting interactions with the environment and interrupting the intimate connection between humans and nature (Ulrich, 2002; Jiang, 2014; Seymour, 2016). Biophilia is one idea as to why nature has a positive cognitive effect on people. Similarly, Ulrich et al. suggested that it is because our evolutionary connection to nature automatically results in stress reducing psychological and physical responses, i.e. the stress-reduction theory (1991). Still others, Kaplan and Kaplan, posited the Attention Restorative Theory (ART); this theory proposes that nature requires involuntary attention, which is effortless, vs. direct attention, which is required for executive functions and requires focus and effort, resulting in fatigue and emotional instability (1989; 1995). According to ART, nature provides an opportunity to pay attention without requiring intense effort, resulting in stress reduction and overall restoration (Kaplan and Kaplan, 1989). Researchers today suggest that it is a combination of all of these ideas that ultimately results in many of the societal benefits of nature (Capaldi et al., 2015).

Including green roofs on urban hospitals could assist in providing these societal benefits to users, as well as fulfilling the human-nature connection and mitigating some of the negative consequences of urbanization and of hospital stays. These benefits might include: reducing emotional distress caused by the hospital atmosphere and improving general mental health; increasing socialization and community connection; increasing physical activity; decreasing cardiovascular and respiratory diseases; increasing motivation to recover; decreasing pain management needs and hospital stay lengths; improving survival rates; increasing employee satisfaction; and increasing education opportunities (Ulrich, 2001, 2002; Warburton et al., 2006; Dravigne et al., 2008; Van den Berg et al., 2007; Lee and Maheswaran, 2011; Cutillo et al., 2015; Monroe, 2015; Warber et al., 2015; Gargari et al., 2016; Barton and Rogerson, 2017; Grunewald et al., 2019; **Figure 3**). Some of these benefits are experienced more heavily by certain populations (Lee and Maheswaran, 2011; Cutillo et al., 2015; Monroe, 2015; McEachan et al., 2016; McCormick, 2017; Enssle and Kabisch, 2020). Additionally, the societal benefits accrued to green roof users are semi-dependent on the accessibility of the green space and the way that a given user is interacting with the green roof, but regardless, the benefits highlighted throughout our review call attention to the societal benefits of green roofs on urban hospitals (Ulrich, 1984, 2002; Loder, 2014; Lee et al., 2015a,b).

Health and Well Being Benefits From Green Roofs for Patients, Employees, and Visitors

Green spaces, such as green roofs, can provide the necessary psychological restoration many patients need in order to physically recover. A lack of interaction with the natural world can increase a person's risk of developing cardiovascular diseases and mental illness, and these effects are part of the nature deficit disorder that shows a direct correlation between a person's overall wellness and the availability of nature in an urban setting (Carpenter et al., 1979; Warber et al., 2015). In order to protect patients in urban hospitals from exhibiting symptoms of nature deficit disorder, patients could be provided physical access to green space. Exposure to green space creates opportunities for quality of life improvements such as psychological restoration and physical activity, socialization, and reconnecting with the natural environment, which all help address the nature deficit disorder and improve mental health (Barton and Rogerson, 2017). Individuals that live in urban areas with more green areas compared with less green areas have "less mental distress, less anxiety and depression, greater well being and healthier cortisol profiles" (Barton and Rogerson, 2017). Access to green space has also been shown to significantly reduce stress and even act as a barrier between stressful life events and poor mental health (Van den Berg et al., 2007). Unsuccessful stress recovery may contribute to chronic arousal, immune suppression, and other aspects of allostatic load, which can worsen physical symptoms and significantly increase a patient's risk of illness (Dantzer et al., 2014). In the context of health care facilities, allowing patients access to green space during their treatment significantly improves their daily mental well being and furthermore, increases their motivation and desire to physically recover (Monroe, 2015). Given the current increase of worldwide mental illness and the proven positive impact of green space interaction on overall well being, introducing green spaces to healthcare settings could provide the opportunity for more interdisciplinary and collaborative treatment options (Marcus and Sachs, 2013; Warber et al., 2015; Barton and Rogerson, 2017).

Green spaces can provide healing and pain reduction benefits related to patient recovery. A study found that patients recovering from gallbladder surgery who had access to nature had "shorter postoperative stays" and "fewer negative evaluation comments" from nurses and staff and "lower scores for minor post-surgical complications" (Ulrich, 2001). The test group that did not have access to green space also required higher doses of pain management during the recovery process (Ulrich, 2001). A similar relationship has also been seen with healing gardens in hospitals. The inclusion of healing gardens in hospitals has been studied for the last few decades and been shown to provide healing benefits such as a reduction in physical symptoms and increased overall wellness (Marcus and Barnes, 1999). Research conducted by Metro Hospital for their own green roof, states that "access to natural scenery from patient rooms may significantly decrease their length of stay and medication use" (University of Michigan Health-West, 2021). The hospital provides viewing access to the rooftop from the majority of their 208 patient rooms

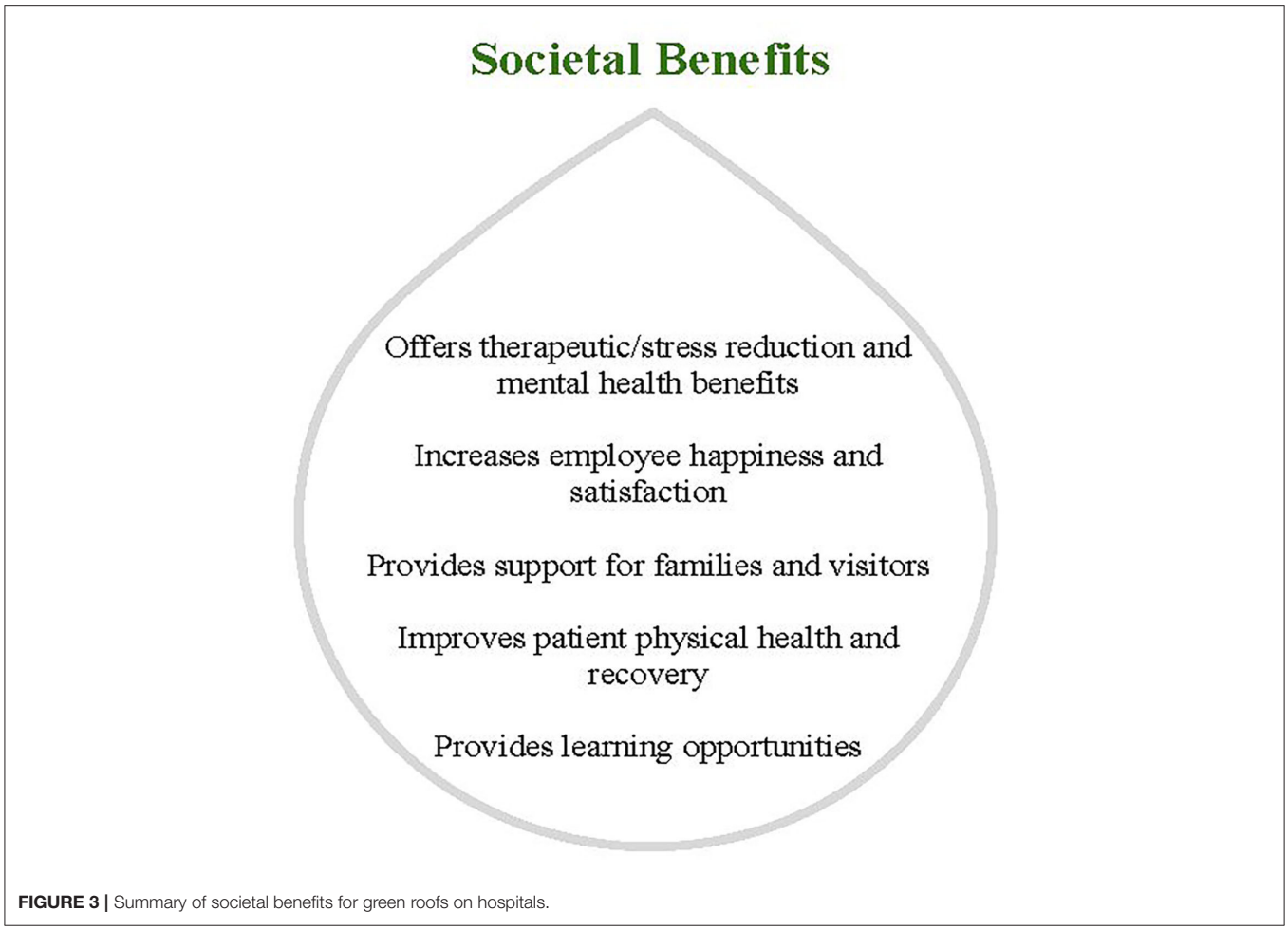

FIGURE 3 | Summary of societal benefits for green roofs on hospitals.

to support patient restoration and stress reduction (University of Michigan Health-West, 2021).

The physical healing benefits from nature have been in part credited to phytoncides, which is an anti-microbial volatile organic compound that comes from plants (Li et al., 2009). Li et al. determined that the many physical benefits received from forest bathing in Japan, including decreased stress hormone levels and increased Natural Killer cell activity, which can help fight off infections and even tumors, are caused by phytoncides (2009). In their study, they specifically reference phytoncides related to pine and citrus. They also found these benefits in individuals exposed to essential oils derived from cedar and cypress while staying in hotels. Many of these same researchers also looked at forest bathing in Agematsu, Japan vs. going on a city tour in Nagoya, Japan and found the previously described health benefits only in those that participating in the forest bathing (Li et al., 2008, 2009). This might suggest that benefits received from phytoncides may not be available on urban green roofs. However, the researchers shared that "[there] are some areas of trees in Nagoya city, but there are almost no trees in the areas visited." Other studies have highlighted the phytoncide benefits of many other plants, such as *Plantago major L.*, which has been found to colonize green roofs in New York City, USA (Kilar and Ruda, 2015; Aloisio et al., 2020). This, along with other studies referencing healing benefits from gardens and green spaces in hospitals (Ulrich, 2001; Warburton et al., 2006; Marcus and Sachs, 2013), suggests that phytoncides can be present on urban green roofs and provide the healing benefits attributed to them in forest locations, although the healing benefits may vary based on the amount of vegetation present. Future research should further consider this question to investigate the presence of phytoncides on green roofs and their ability to provide healing to users.

Regardless, green roofs can offer patients, families, and employees an escape from stressful hospital settings. Because of this, the feelings of "fear, anger, and sadness" associated with hospital stays have been recorded to decrease (Ulrich, 2002). After obtaining post-occupancy evaluations from 1400 visitors of healing gardens surrounding a pediatric cancer center, it was found by researchers that emotional distress and pain was lower in the gardens than inside the hospital (Sherman et al., 2005). One study reviewed unprompted comments in a visitor's book at Lady Cilento Children's Hospital in Brisbane, Australia and learned that patient and family members that interacted with the healing garden received "emotional respite" and greatly appreciated a chance to be outside, in nature (Reeve et al., 2017). The physical movement and exercise aspect as well as

a positive distraction with nature contribute to the patients' ability to let go of their diagnosis-related stress and connect to something else in their environment (Ulrich, 1999). While not connected directly to hospitals, people's favorite places are often natural areas, which provide an opportunity for relaxing, restoring, and working through their worries (Korpela and Hartig, 1996; Korpela et al., 2001). This is especially important in stressful hospital settings and investigating patients', visitors', and employees' favorite spaces in hospitals with green roofs, as well as the impact of those areas, may be a future area of research. When patients and families reflected on their hospital experiences, the increased quality of care as a result of green spaces ultimately resulted in increased patient and family satisfaction with the institution as well (Ulrich et al., 2004).

Including green roofs on hospitals can result in better physical health for all users, including patients, visitors, and employees. The inclusion of green spaces in urban development tends to increase physical activity, offering opportunities for "green space exercise" such as walking (Lee and Maheswaran, 2011). People who actively utilize green spaces reap the many benefits associated with increased physical activity including decreased risk of cardiovascular disease, hypertension, diabetes, specific cancers (breast and colon cancer), osteoporosis and other chronic diseases, as well as decreases in muscle tension, blood pressure, and brain electrical activity" (Ulrich, 2001; Warburton et al., 2006). Additionally, green roofs increase biodiversity, which has been directly connected with human well being (Marcus and Sachs, 2013). Specifically, increased biodiversity on green roofs includes microbial biodiversity, which can provide physical benefits to humans such as a reduction in respiratory and allergic diseases (Sandifer et al., 2015; Aerts et al., 2018). John Theurer Cancer Center and Rady Children's Hospital both highlight the physical benefits of their green roofs, mentioning the inclusion of walkways and areas for playing for young patients (Greenroofs.com, 2021b; Rady Children's Hospital-San Diego, 2021).

The previous examples and journal articles related mostly to green spaces in urban settings or green spaces in hospitals. While there has been limited research explicitly considering the effect of green roofs on an individual's physical and mental health, a few studies have indicated positive effects between the two (Ghazalli et al., 2019). One study surveyed users on their perceived benefits from the green roof including socialization, stress reduction, and recreational activities, and found high satisfaction rates, while another study found that participants increased their task performance with just a 40-second view of a nearby green roof (Lee et al., 2015b; Rezaei et al., 2020). Other studies have also investigated the reduction in noise pollution specifically because of green roofs. Greater levels of noise can disrupt or lower sleep quality and relaxation causing increased heart rate and frustration to patients negatively affecting their health and their experience with the hospital (Ulrich, 2001; Coutts and Hahn, 2015). The design structure of a green roof offers noise reduction in emergency and patient rooms to improve sleep quality and relaxation through their ability to absorb, reflect, and deflect different sound frequencies to minimize the noise pollutants that affect patients' satisfaction, happiness, and recovery (Coutts and Hahn, 2015; Feng and Hewage, 2018; Grunewald et al., 2019; **Figure 6**). Sharp Memorial Hospital's green roof was constructed on top of their emergency room to help mitigate noise pollution to better their patients' experience (Greenroofs.com, 2021e).

In the examples of green roofs on hospitals that we investigated, Sharp Memorial Hospital's green roof was built to "bring joy and assist in the healing process of patients" and a main reason that John Theurer Medical Center has a green roof is to "make the patient experience as pleasant and stress-free as possible" (Greenroofs.com, 2021b,e). Both of these hospitals, as well as the other hospitals we examined for this review, emphasize both the physical and mental benefits as key reasons for the construction of their green roofs. Reintroducing green space to healthcare care plans can support the innate human-nature connection and reinforce greater overall well being in institutions made for healing.

Access to green space has been proven to benefit people in general and has been further shown to have positive benefits on specific, vulnerable populations. Green space has been associated with improved mental well being, cognitive development, and overall health of children (McCormick, 2017). Rady Children's Hospital's green roofs focus almost exclusively on the mental health benefits received by their young patients; the green roof is a place for families and patients to "relax, enjoy the outdoors, and take their minds off of the medical care" (Rady Children's Hospital-San Diego, 2021). It serves as a "refuge for [patients and their family members] to get away from the stress of the high-tech environment of the Hospital" (Rady Children's Hospital-San Diego, 2021). For youth with autism, green space was directly associated with reducing anxiety symptoms (Larson et al., 2018). Pregnant women with substantial green space around them reported 18–23% less depressive symptoms than those with less available green space (McEachan et al., 2016). For elderly populations, green spaces allow ample opportunity for connectivity, social interaction and physical activity which contribute to better mental and physical well being (Enssle and Kabisch, 2020). The availability of green space has been shown to increase survival rates of elderly populations and decrease mortality rates of stroke patients (Lee and Maheswaran, 2011). In studies of dementia patients, horticulture therapy has shown to positively influence eating and sleeping patterns, emotional stability, physical activity and mobility, and self-esteem and control (Lu et al., 2020). Horticulture therapy is also used to treat psychological disorders such as Major Depressive Disorder, Bipolar Disorder, and Schizoaffective Disorder (Monroe, 2015). Green space has also been found to be beneficial in cancer treatment. By adding gardening to the care of adult cancer patients, researchers found "significant improvements in spiritual well being, quality of life, cancer-related fatigue, Natural Killer cell activity, tension, anxiety and confusion" (Cutillo et al., 2015). The green roof on John Theurer Cancer Center is purposefully viewable from the room where patients receive their chemotherapy and the hospital uses the herbs and vegetables grown on the roof in the cooking classes for the cancer patients and their families (Williams, 2011). In the case of hospice patients, green space has been shown to decrease suffering and

improve quality of life for patients, their families, and caregivers; and researchers believe that including green design "should be considered when making design decisions for care facilities to improve physical, psychological, social, and spiritual needs at end of life" (Sagha Zadeh et al., 2018).

Education and Employee Retention With Green Roofs

Green roofs can also provide an educational benefit, particularly to pediatric patients. Children can learn about the importance of nature as an immersion experience during their hospital stay, an experience that they might not otherwise have by living in an urban region (Architonic, 2014; Warber et al., 2015; Greenroofs.com, 2021d). Urban areas lack biodiversity: green roofs provide an opportunity for insects and birds to be part of the roof's ecosystem and patients, specifically pediatric patients, can learn the importance of plant biodiversity, pollination, and microorganisms through this experiential learning (Architonic, 2014; Gargari et al., 2016; Grunewald et al., 2019; Greenroofs.com, 2021d). The educational aspects of green roofs offer patients and families an opportunity to separate themselves from their illness or disease and focus on the immersion of nature and its many learning facets. Schools around the world, including the Garden School in Beijing, China and PS 41 in New York City, USA, have designed green roofs to incorporate environmental education into the everyday lives of their students living in urban cities to promote environmental stewardship (Architonic, 2014; Greenroofs.com, 2021d). Similar concepts can be incorporated into the designs of urban green roofs on healthcare facilities. As a leading hospital in sustainability initiatives, HUMC constructed the John Theurer Cancer Center roof garden in 2011 to offer therapeutic healing services to their cancer patients (Greenroofs.com, 2021b). John Theurer Cancer Center's "demonstration vegetable garden" on their green roof is utilized as an educational tool for dietitians to teach oncology patients how to garden and cook healthy foods to promote healing (Association of American Medical Colleges., 2021; Greenroofs.com, 2021b).

Additionally, for healthcare employees, interaction with green space has been shown to significantly decrease stress and depression both while working and upon leaving (Cutillo et al., 2015). Employee well being, satisfaction, and productivity rely heavily on their workplace environment (Dravigne et al., 2008). Retention rates for healthcare workers has dropped within the last few years due to understaffing, overworking, long rotating shifts, and the high work demand required in a hospital (Ulrich, 2002; McDermid et al., 2020): by 2025, the United States is estimated to "have a shortage of 150,000 physicians" that will lead to an increase of "medical errors and health-associated infections" (Becker's Hospital Review., 2021). Specifically, in urban regions where green space is limited, green roofs provide an opportunity to increase employee satisfaction and improve retention rates by offering access to nature (Ulrich, 2002; Dravigne et al., 2008). A study conducted on employee perceptions of job satisfaction found a significant difference ($p < 0.05$) between employees working in office spaces with some form of access to nature (live plants or window views) vs. those without access (Dravigne et al., 2008). Healthcare workers who utilize green space during work hours can decompress from work-related stressors associated with a hospital and can therefore provide better care to their patients (Ulrich, 2002; Dravigne et al., 2008). Hospitals that included outdoor space with picnic tables and benches in their green roof designs for their employees are HUMC, Metro Health, Fletcher Allen Hospital, and Rady Children's Hospital (Greenroofs.com, 2021a,b,c; Rady Children's Hospital-San Diego, 2021).

Considering Design and Accessibility for Green Roof Implementation

Green spaces increase satisfaction and healing for hospital end users, which is why the majority of patients and staff are demanding green space be implemented in future healthcare institution projects (Wood et al., 2016). As Clare Cooper Marcus stated, "Healing gardens have come of age. Due in part to a growing body of evidence on the health benefits to patients, staff, and visitors, they are appearing in hospitals, senior facilities, cancer facilities, and memory care units nationwide" (Marcus, 2016). In the context of hospital infrastructure, designing with the mentality that 'everyone counts' can improve both the patient and staff well being, as well as patient healing and stress reduction (Chias and Abad, 2017). This idea is referred to as patient-centered and back-of-house design, meaning the needs of the patients and employees of the hospital are kept in mind during the design process to maximize the functionality of the space. For patient care and hospital success, the presence of nature integrated into the architecture of a hospital has been proven to accelerate a patient's recovery from surgery as well as the hospital staff's mental fatigue (Chang and Chien, 2017). When considering the design of green roofs, healthcare facilities must weigh many factors including available space, different accessibility options, and desired benefits. Healthcare facilities can implement green roofs and green spaces in hospitals to be accessible to patients. Upon considering the accessibility, hospitals must also determine what kind of therapeutic activities they want patients and staff to be able to partake in; such as horticulture therapy vs. space for physical exercise, or a combination of different potential benefits of their green space. Specifically for urban hospitals, green spaces like green roofs, green walls, and green facades are effective for the incorporation of synergy between plant life and functional healthcare when physical space beyond the hospital footprint is limited (Williams et al., 2019). In a study done on the psychological benefits of green spaces, it was determined that the functionality and characteristics of urban green spaces, such as being accessible, were the true determinate of its success (Lee et al., 2015a).

In many of the research articles and our examples of green roofs on urban hospitals, there are varying focuses on accessible and inaccessible green spaces. Fletcher Allen Hospital's green roof is a physically accessible green roof where patients, visitors, employees, and the general public can walk around the space and even grow vegetables (Greenroofs.com, 2021a). Sharp Memorial Hospital's green roof, on the other hand, cannot be

FIGURE 4 | A patient's view of Carley's Magical gardens located at Rady Children's Hospital, San Diego, California (photograph used with permission, Nelson, 2004).

accessed but can be viewed through windows in patients' rooms (Greenroofs.com, 2021e). Accessible green roofs are usually preferred by users over inaccessible green roofs (Loder, 2014). In 1998, the San Diego Children's hospital, now known as Rady Children's Hospital, opened the Leichtag Family Healing Garden to aid in enhancing the patient and family experience during their stay with the hospital by following their mission to "consistently nourish the physical, emotional, mental and spiritual needs of children, their families and our staff through our healing environment" (Rady Children's Hospital-San Diego, 2021; **Figure 4**). The whimsical gardens were originally designed to offer direct access to pediatric patients and families staying in the postoperative medical surgical rooms "to provide a sense of caring and stability; a place where healing occurs" (Sadler, 2001).

Though accessible spaces are often preferred and may offer a wider range of benefits, such as physical activity and hands-on educational benefits, inaccessible green spaces in healthcare facilities, where patients can only view the natural scene, are still found to be significantly beneficial for patient care and emotional wellbeing. Ulrich found that patients were relieved from hospital stressors within as little as 3 to 5 mins after simply viewing nature from their hospital room (Ulrich, 2002). A later study indicated that those that can physically access green roofs obtain greater stress reduction than those that cannot, but those that can only view green roofs still benefit from the calming and engaging scenery (Loder, 2014). Along with stress relief, viewing access to natural environments and green space in a hospital setting has been shown to promote positive thinking to create a "pleasant distraction" from the stressful environment of a hospital to promote healing (Ulrich, 1984, 2002; **Figure 3**). A study conducted by Ulrich, compared the hospital stays of two postoperative groups consisting of patients who had viewing access to a natural landscape vs. those viewing a brick wall outside of their hospital room (Ulrich, 1984). This study concluded that postoperative stays of the patients with viewing access to green space were shorter than patients facing the brick wall. The nature-facing group was also found to have fewer post-surgical complications, to require lower doses of pain medication, and to receive more positive notes from the nursing staff indicating a direct correlation between positive thinking and decreased anxiety through access to nature scenes (Ulrich, 1984, 2002).

Sharp Memorial Hospital's unique extensive rooftop garden design is not physically accessible to patients but provides viewing access from patient rooms of native Southern California plants designed to mimic "Beethoven's 9th Symphony 'Ode to Joy'" (Greenroofs.com, 2021e). Sharp Memorial Hospital has earned the title of the "Most Beautiful Hospital in the

FIGURE 5 | A patient's view of native Southern California plants used in the design of the extensive green roof garden located on Sharp Memorial Hospital's emergency room (photograph used with permission, Schmidt Design Group, 2021).

World" by HealthExecNews.com in 2012 for their commitment to "patient-centered care and aesthetic beauty" (NBC 7 San Diego., 2021). Those involved in the design and execution of the Healing Garden at Fletcher Allen Hospital understood the psychological benefits offered by green spaces. Because of this, the healing garden, while also physically accessible, was designed to be visible to patients from their rooms offering visual benefits of green space including feelings of tranquility, higher rates of healing and positive mindsets about their diagnosis (Ulrich, 2002; Pouya and Demirel, 2015; Warber et al., 2015; Greenroofs.com, 2021a; **Figure 5**). Regardless of accessibility or preferences in design, green roofs in hospitals offer a wide range of benefits to hospital-end users and should be considered in future healthcare projects.

ECONOMIC BENEFITS OF GREEN ROOFS ON URBAN HOSPITALS

The planning and success of implementing a green roof is the responsibility of a hospital's project manager who takes into account the multiple facets of the project itself, the specific organization's needs, and the external environment (Santos et al., 2014). Project managers act as the liaison between internal departments of the hospital, including higher level management who accept or reject the proposal, the Environmental Health and Safety Department, the Foundation, and Patient Satisfaction (Santos et al., 2014). Project managers also must work with outside vendors that include architects and landscape designers that specialize in green roofs for the design, timeline, and construction of the project and additional sub-contractors for supplies and future maintenance.

When determining the budget allocated for construction of a green roof, project managers must consider if this space is intended to be physically or visually accessible, the size of the project overall, and the potential limitations (Sadeghian, 2017). The initial costs of constructing a green roof vary based on the "growing medium, type of roofing membrane, quantity of plants and drainage system" (Li and Yeung, 2014). Extensive roofs are preferred for facilities looking to provide patients with viewing access of the green space and minimal maintenance cost and upkeep (Gargari et al., 2016). Alternatively, intensive green roofs are a more complex system with a higher initial cost but offer a larger variety of benefits such as more opportunity for larger and more diverse vegetation. Estimates of green roof installation costs vary widely by source and location (Manso et al., 2021). In the United States in 2009, the average cost of an extensive green roof

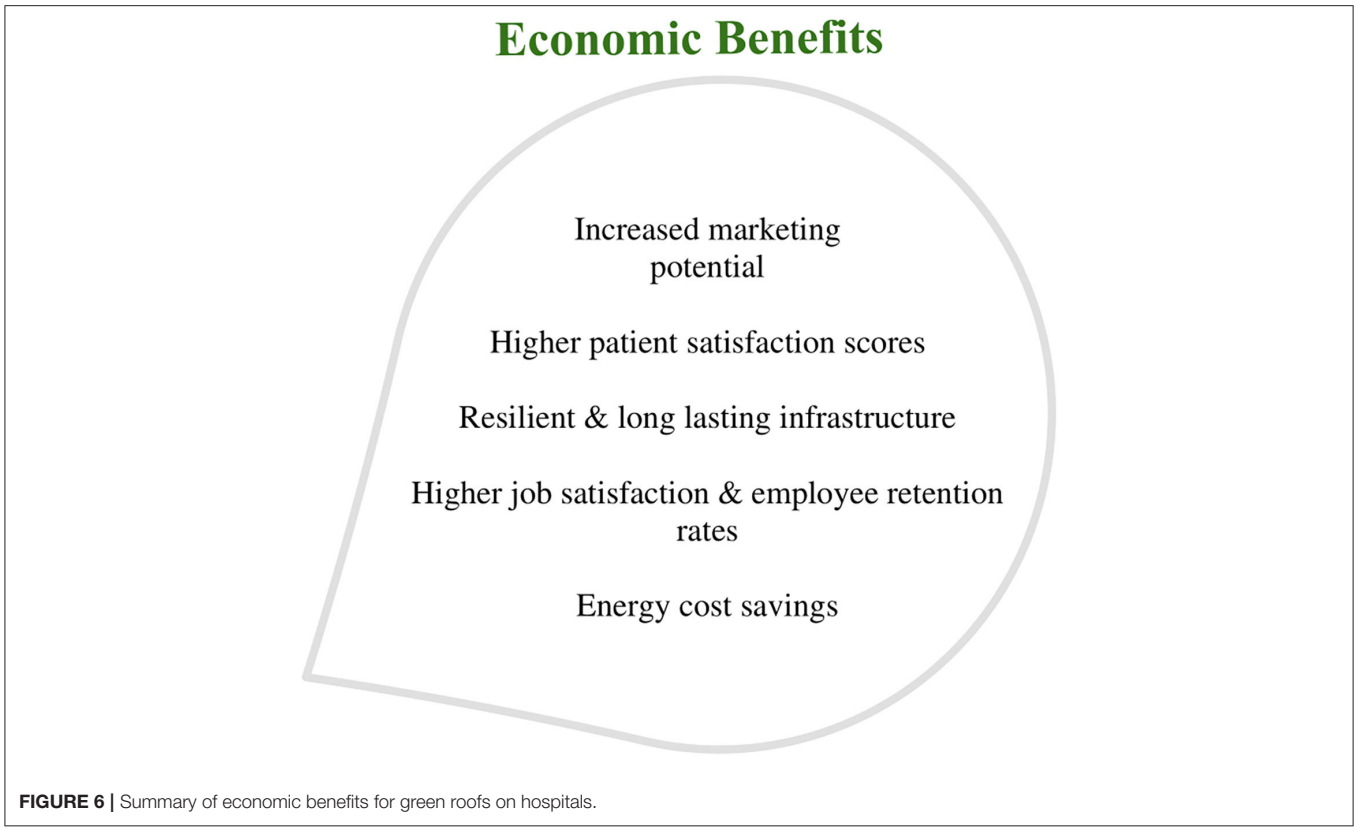

FIGURE 6 | Summary of economic benefits for green roofs on hospitals.

is \$8.36 per yr^2 (\$10 per m^2) compared to an intensive green roof that averages \$255.75 per yd^2 (\$270 per m^2) (Li and Yeung, 2014). Manso et al. reviewed journal articles related to the installation costs of green roofs from 2008 to 2018 and calculated the average extensive green roof installation to cost \$94 per yd (\$112 per m) and the average intensive green roof installation to cost \$342 per yd^2 (\$409 per m^2) (2021). The price of installation for green roofs has been found to decrease between 33% to 50% once the industry has been established (Feng and Hewage, 2018). Because of this, in Germany, the average price of green roof installation ranges from \$12.54 to \$37.62 per yd^2 (\$15 to \$45 per m^2). Both intensive and extensive roofs require different maintenance and operational costs taking into consideration the size and characteristics of the roof itself, vegetation used, and local climate (Feng and Hewage, 2018). Fletcher Allen Hospital and HUMC constructed intensive roofs while Rady Children's Hospital, Sharp Memorial, and Metro Health opted for extensive roofs (Greenroofs.com, 2021a,b,c,e; Rady Children's Hospital-San Diego, 2021).

Costs for green roof infrastructures in the United States will likely decrease overtime as they grow in popularity similar to that experienced in Germany, where lower green roof pricing is a direct result of their "ongoing research and development" over the last two decades (Coutts and Hahn, 2015). Economic benefits of installing green roofs on hospitals comes both indirectly from patient experiences and increased marketing potential and directly from cost savings through reductions in energy use and longer lasting roofs (Coutts and Hahn, 2015; Ganguly et al., 2016; Feng and Hewage, 2018; Shafique et al., 2018; Grunewald et al., 2019; Kronthal-Sacco et al., 2020; Mutani and Todeschi, 2020; **Figure 6**). Limited research is available on the planning and success of project management in healthcare with even less scientific evidence of the project development, success, or extended maintenance of green roofs on hospitals (Santos et al., 2014; Dauda and Alibaba, 2019; Dobin and Lazar, 2020). Additional resources are needed for project and facility managers at hospitals to better understand the costs and steps of green roof projects, including resources for the development of proposal and project outlines to ensure project success.

Indirect Economic Benefits

The inclusion of green roofs provides several opportunities to increase a hospital's overall satisfaction scores, including production of local food, reduced noise pollution, and improved employee satisfaction. The increase in a hospital's satisfaction scores can result in increased marketing potential, greater employee retention, and better opportunities for future funding. Fletcher Allen Hospital provides its patients with nutrient dense foods including local vegetables and herbs that are grown on their roof (Greenroofs.com, 2021a). Similarly, HUMC grows produce and herbs on their rooftop garden to teach oncology patients the importance of healthy foods (Greenroofs.com, 2021b). This feature provides patients with locally sourced produce that supports their healthcare experience, increasing the likelihood of better scores that can lead to increased funding

and marketability. A patient's satisfaction with their hospital stay also relies heavily on their comfort with the hospital atmosphere (Zusman, 2012). Hospitals located in urban environments have higher levels of noise from both inside factors from medical equipment, for instance, and outside noise pollutants including traffic and construction, creating an "annoyance among patients and perceived staff" (Ulrich, 2001; Coutts and Hahn, 2015). Green roofs have the functionality of minimizing noise pollution and thereby increasing patients' comfort (Coutts and Hahn, 2015; Feng and Hewage, 2018; Grunewald et al., 2019). Lastly, higher employee satisfaction and thus better retention rates also support better patient care and overall satisfaction with the hospital (Ulrich, 2002; Dravigne et al., 2008). While no research articles directly linking hospital employee satisfaction and retention were identified for this review, several studies link employee satisfaction and loyalty in office spaces and hotels to access to some form of nature (Dravigne et al., 2008; Han et al., 2020). In 2018 Metro Health, a leading hospital in green initiates and home to a green roof, ranked one of "Northeast Ohio's 99 Best Places to Work" for the 15th time by the Employee Resource Council (MetroHealth., 2018).

As the concepts of global warming and climate change become more widely known, consumers indicate preferences to support companies or organizations that are implementing sustainability practices (Kronthal-Sacco et al., 2020). Green roofs offer opportunities for hospitals to market their green initiatives to consumers, including patients and potential employees (**Figure 6**). With the growing consumer demand for green initiatives, the addition of green space to buildings has been shown to increase the property value and support positive public relations (Feng and Hewage, 2018). Within one year of the Leichtag Family Healing Garden at Rady Children's Hospital, a second garden, Carley's Magical Gardens, was built and fully funded by donations and fundraising led by a family whose daughter was treated at the hospital for leukemia (Sadler, 2001). The family had such a positive experience with the original Leichtag Family Healing Garden, they felt compelled to fund the opportunity for more green space within the hospital. Rady Children's Hospital concluded that green infrastructure increased the marketing potential for employees and patients as a benefit to working or seeking care at this facility. Within four years of the project, "specialty outpatient volume increased by 70 percent" (Sadler, 2001). Similarly, the hospital's emergency room equipped to handle 25,000 visits per year exceeded 55,000 visits in response to patient satisfaction and referrals. Patients in the community began to choose Rady Children's Hospital over other competing pediatric hospitals, in part because of their green roofs.

Direct Economic Benefits

In the coming years, hospitals will be required to expand and to use larger amounts of energy and fossil fuels in order to accommodate the growing urban populations (Mutani and Todeschi, 2020). Offering comfortable climate control while mitigating the energy required to run a hospital can be accomplished through the establishment of a green roof. Based on varying climates, green roofs have been recorded to save institutions an average of \$0.15 - \$0.57 per yd^2 (\$0.18–\$0.68 per m^2) in cooling and \$0.18 per yd^2 (\$0.22 per m^2) in heating annually (Coutts and Hahn, 2015; **Figure 6**). In order to combat the energy inefficiency traits of traditional roofing, larger amounts of fossil fuels are required to regulate temperatures inside of the building: traditional heating and cooling systems are considered active techniques that require the use of primary energy consumption, generally primarily coming from burning fossil fuels, to cool and heat a building (Shafique et al., 2018). Compared to active cooling techniques, green roofs use naturally occurring passive cooling techniques that include "shading, evapotranspiration, insulation, increase in thermal mass, and reduction of heat loss through radiation" mimicking ecosystems (Feng and Hewage, 2018). The vegetation and planting materials used in the construction of a green roof assist in maintaining comfortable temperatures inside of the building by storing thermal energy and releasing it slowly back into the atmosphere (Ganguly et al., 2016). The naturally occurring insulating properties of plants and vegetation create a barrier between the sun and a building, limiting the amount of solar radiation that is absorbed (Shafique et al., 2018). Improved insulation from their green roof has saved Metro Health University of Michigan Health money by limiting the amount of energy required to comfortably maintain temperatures inside of the hospital, minimizing the institution's carbon footprint and costs for fossil fuels (Feng and Hewage, 2018; University of Michigan Health-West, 2021). In another example, as a result of the heating and cooling insulation provided by the structure of HUMC's green roof, the hospital requires lower energy output resulting in a reduction of greenhouse gas emissions and fossil fuels required to heat and cool the building (Greenroofs.com, 2021b).

Compared to traditional roofing, green roofs offer urban hospitals a resilient and long-lasting alternative that, over time, can save the institution money and resources (**Figure 6**). Green roofs have been documented to have a longer lifespan compared to traditional roofing because of the design qualities that protect the structure against "diurnal fluctuations, UV radiation, and thermal stress" (Feng and Hewage, 2018; Mutani and Todeschi, 2020). The average lifespan of a conventional roof used on commercial buildings typically lasts between 10 and 30 years based on the climate of the region and construction materials (General Services Administration, 2011; Grunewald et al., 2019). Alternatively, the average lifespan of a green roof lasts between 40 and 50 years or more depending on the design structure and aging qualities of the membrane (General Services Administration, 2011; Feng and Hewage, 2018). European countries such as Germany, have been utilizing green roof designs on urban buildings throughout the 1900s (Grunewald et al., 2019). Green roofs in Berlin have been reported to be lasting over 90 years with minimal upkeep or replacement compared to traditional roofs that require replacing every few decades (Grunewald et al., 2019). The majority of green roofs discussed in this paper were completed between 10 and15 years ago, while the Leichtag Family Healing Garden and Carley's Magical Gardens were built over 20 years ago (Sadler, 2001).

GREEN ROOFS HELP URBAN HOSPITALS ACHIEVE SUSTAINABILITY ACROSS THREE PILLARS

The three pillars of sustainability were addressed within each of the reported example hospitals, drawing similarities among hospitals with the strong benefits afforded them by implementing green roofs in their structural designs (**Table 2**). The environmental, societal, and economic benefits noted in the research articles and displayed in the hospital green roof examples can be summarized into 13 specific benefits: biodiversity, stormwater mitigation, urban heat island effects, air filtration, therapeutic qualities/stress reduction for patients, family/visitor support, employee happiness/satisfaction, physical health benefits, learning opportunities, patient satisfaction, employee retention rates, energy efficiency, and infrastructure lifespan. These benefits can further be categorized into seven common themes: resiliency, climate mitigation, emotional well being, physical wellbeing, educational properties, marketing/public relations, and cost effectiveness (**Table 2**). In combining the scientific research of green roofs and examples of green roofs on urban hospitals, we have seen that the addition of green roofs creates mutually beneficial or symbiotic relationships between the local ecosystems and the associated communities that can lead to increased funding and financial gain for the hospital. This review of green roof implementation on urban hospitals provides project managers, decision makers, and government officials with a more complete set of baseline information to support resiliency efforts from the three pillars of sustainability discussed.

All but one of the hospital's green roofs had an emphasis on environmental benefits (**Table 2**). HUMC's John Theurer Cancer Center and Metro Health University highlighted all four of the environmental benefits identified in research articles presented in this review: biodiversity, stormwater mitigation, urban heat island effects, and air filtration. Biodiversity was the environmental benefit least discussed by the hospitals in the examples. Of the societal benefits, all of the hospitals emphasized the therapeutic benefits as an asset of their green roofs (**Table 2**). This was the only benefit of any of the three pillars that was acknowledged by each of the hospitals. HUMC and Rady Children's Hospital both noted four societal benefits from their green roofs. The example focusing on Rady Children's Hospital almost solely focused on the societal benefits of their green roofs, only emphasizing one other economic benefit. The economic sub-benefits identified through research articles - higher patient satisfaction, employee retention rates, energy efficiency, and longer infrastructure lifespan - were all expressed as benefits by HUMC from their green roof (**Table 2**). Each of the other four medical centers mentioned between one to three of the economic benefits, with energy efficiency and longer infrastructure lifespan being the most prominent economic benefits.

HUMC's green roof acknowledged 12 of the 13 sustainability benefits found in the journal articles. Interestingly, HUMC's green roof was constructed most recently out of all of the example hospitals. Rady Children's Hospital, with the oldest construction years, focused most on the societal benefits while Metro Health University focused more on the environmental benefits and a few economic benefits. The final two example hospitals, Fletcher Allen Hospital and Sharp Memorial Hospital, highlighted seven and eight of the 13 sustainability benefits respectively, spread across the three categories. It appears that the hospital green roofs constructed later in time- Fletcher Allen Hospital constructed in (2010), Sharp Memorial Hospital constructed in (2010), and HUMC's John Theurer Cancer Center constructed in (2011)- appear to focus more evenly on each of the three pillars of sustainability than the other hospitals. While this is a very small sample size it does speak to the growing understanding that the needs of our communities require holistic solutions. And while none of the examples expressed success with all of the benefits identified with the research articles and some hospitals favored certain benefits, the benefits are intrinsically connected (**Figure 7**). This means that the benefits were quite possibly actualized through the green roofs without being a primary focus for the hospital.

In addition to categorizing the sustainability benefits from green roofs identified through the research articles and real-life examples, the economic costs of the green roofs were also considered amongst the benefits of green roofs. Overall, 13 sustainability benefits were highlighted during this review, some of which have direct monetary benefits while others have potential indirect monetary benefits. Direct costs associated with the green roofs include installation, maintenance, replacement of plants or materials if needed, and employment costs for individual(s) to provide upkeep (**Table 3**). In order to determine if installing a green roof is in the best interest of a hospital, the decision makers must weigh these direct costs against the potential benefits. While a complete cost-benefit analysis was beyond the scope of this review paper, similar studies focusing on the cost-benefit analysis of green roofs show that the benefits associated with green roofs, while intangible, did surpass the initial costs (Nurmi et al., 2016; Feng and Hewage, 2018; Shin and Kim, 2019). As green roofs become more popular, the construction costs are likely to decrease (Shin and Kim, 2019). Based on a green roof's longevity averaging between 40 and 55 years, the amount of time it takes to pay off the initial costs of a green roof is significantly less than the average lifespan of the green roof (Nurmi et al., 2016; Feng and Hewage, 2018). Our simplified cost-benefit analysis of the sustainability benefits accrued from green roofs (**Table 3**) also indicates that the benefits outweigh the costs.

There are, however, many areas that are in need of future research related to green roofs on hospitals. Journal articles related to societal benefits, specifically related to therapeutic/mental and physical health benefits outnumbered journal articles related to other topics, specifically environmental and economic areas of research. Additionally, real world examples, such as those related to the hospitals that were shared in this paper, are not as clear cut as scientific experiments outlined in journal articles and have many influencing factors. Because of this it is difficult to know the true, total impact that green roofs are having on users, the environment, and economy.

TABLE 2 | The three pillars of sustainability, comparing the findings from example hospitals and the journal articles.

Three pillars of sustainability	Common themes	Journal article findings of green roofs	Findings from examples of green roofs on urban hospitals				
			Fletcher Allen Hospital	Hackensack University Medical Center	Metro Health University	Rady Children's Hospital	Sharp Memorial Hospital
Environment	Resiliency	Biodiversity[a]		X	X		
		Stormwater mitigation[b]	X	X	X		X
	Climate mitigation	Urban heat island effects[c]		X	X		X
		Air filtration[d]	X	X	X		X
Society	Emotional wellbeing	Therapeutic qualities/stress reduction[e]	X	X	X	X	X
		Family/visitor support[f]		X		X	
		Employee happiness/ satisfaction[g]		X		X	
	Physical well being	Physical health benefits[h]				X	X
	Educational properties	Learning opportunities[i]	X	X			
Economy	Marketing/PR	Higher patient satisfaction[j]		X		X	X
		Employee retention rates[k]	X	X			
	Cost effectiveness	Energy efficiency[l]	X	X	X		X
		Greater infrastructure lifespan[m]	X	X	X		X

[a] *Brenneisen, 2006; Coutts and Hahn, 2015; Aerts et al., 2018; Partridge and Clark, 2018; Alosio et al., 2019; Partridge et al., 2020; Wooster et al., 2022.*

[b] *Benedict and McMahon, 2002; Brenneisen, 2006; Coutts and Hahn, 2015; Shafique et al., 2018; Castleton et al., 2019; Knapp et al., 2019; Mutani and Todeschi, 2020.*

[c] *Rakhshandehroo et al., 2015; Bevilacqua et al., 2017; Feng and Hewage, 2018; Shafique et al., 2018; Cai et al., 2019; Castleton et al., 2019; Mutani and Todeschi, 2020; Aletba et al., 2021.*

[d] *Yang et al., 2008; Hayati and Sayadi, 2012; Coutts and Hahn, 2015; Gourdji, 2018; Seyedabadi et al., 2021.*

[e] *Carpenter et al., 1979; Ulrich, 1984, 1999, 2002; Kaplan and Kaplan, 1989; Ulrich et al., 1991; Kaplan, 1995; Korpela and Hartig, 1996; Korpela et al., 2001; Sherman et al., 2005; Van Den Berg et al., 2010; Marcus and Sachs, 2013; Loder, 2014; Capaldi et al., 2015; Coutts and Hahn, 2015; Lee et al., 2015b; Monroe, 2015; Warber et al., 2015; McEachan et al., 2016; Barton and Rogerson, 2017; Chang and Chien, 2017; Chias and Abad, 2017; Reeve et al., 2017; Feng and Hewage, 2018; Ghazalli et al., 2019; Grunewald et al., 2019; Xue et al., 2019; Lu et al., 2020; Rezaei et al., 2020.*

[f] *Sadler, 2001; Ulrich, 2001, 2002; Ulrich et al., 2004; Sandifer et al., 2015; Reeve et al., 2017; Sagha Zadeh et al., 2018.*

[g] *Ulrich, 2002; Dravigne et al., 2008; Cutillo et al., 2015; Marcus, 2016; Wood et al., 2016; Chang and Chien, 2017; Chias and Abad, 2017; McDermid et al., 2020.*

[h] *Carpenter et al., 1979; Marcus and Barnes, 1999; Ulrich, 2001, 2002; Warburton et al., 2006; Li et al., 2009; Lee and Maheswaran, 2011; Marcus and Sachs, 2013; Loder, 2014; Coutts and Hahn, 2015; Monroe, 2015; Pouya and Demirel, 2015; Sandifer et al., 2015; Warber et al., 2015; Marcus, 2016; Chang and Chien, 2017; Chias and Abad, 2017; Aerts et al., 2018; Feng and Hewage, 2018; Grunewald et al., 2019; Callaghan et al., 2020.*

[i] *Warber et al., 2015; Gargari et al., 2016; Grunewald et al., 2019.*

[j] *Sadler, 2001; Ulrich, 2002; Dravigne et al., 2008; Zusman, 2012; Coutts and Hahn, 2015; Feng and Hewage, 2018; Grunewald et al., 2019.*

[k] *Ulrich, 2002; Dravigne et al., 2008; Han et al., 2020; Kronthal-Sacco et al., 2020.*

[l] *Coutts and Hahn, 2015; Ganguly et al., 2016; Feng and Hewage, 2018; Shafique et al., 2018.*

[m] *Feng and Hewage, 2018; Grunewald et al., 2019; Mutani and Todeschi, 2020.*

Future research should investigate questions related to this, such as studying patient and employee satisfaction before and after the installation of a green roof; employee retention before and after green roof installation; how frequently users visit the green roof and for how long, and how this influences the received benefits; the space of green roofs required for a hospital, its users, and the community to experience a given benefit; the presence of phytoncides and their healing capabilities on hospital green roofs; the selection of plant types for a green roof and its impact on the received benefits; the difference in experienced benefits between patients that visually interact with the green roof vs. physical interact vs. both; the amount of government and private funding received by hospitals before and after green roof installation. Lastly, the implementation of sustainability has come under scrutiny in recent years for focusing too much on reduction of harm rather than regeneration (Gou and Xie, 2017). Individuals have called for more focus on regenerative design vs. sustainability. We acknowledge that there is always room to improve and also that current efforts are moving forward rapidly. Efforts related to sustainability will certainly continue to evolve and improve in the coming years. The best way to achieve holistic success is through action such as that recommended in this paper, with those involved focusing on current and future population's universal needs.

PRESCRIBING GREEN ROOFS FOR URBAN SUSTAINABILITY

Current institutionalized healthcare systems have taken the therapeutic and emotional aspects of healthcare out of the equation to increase the efficiency of the corporation. The

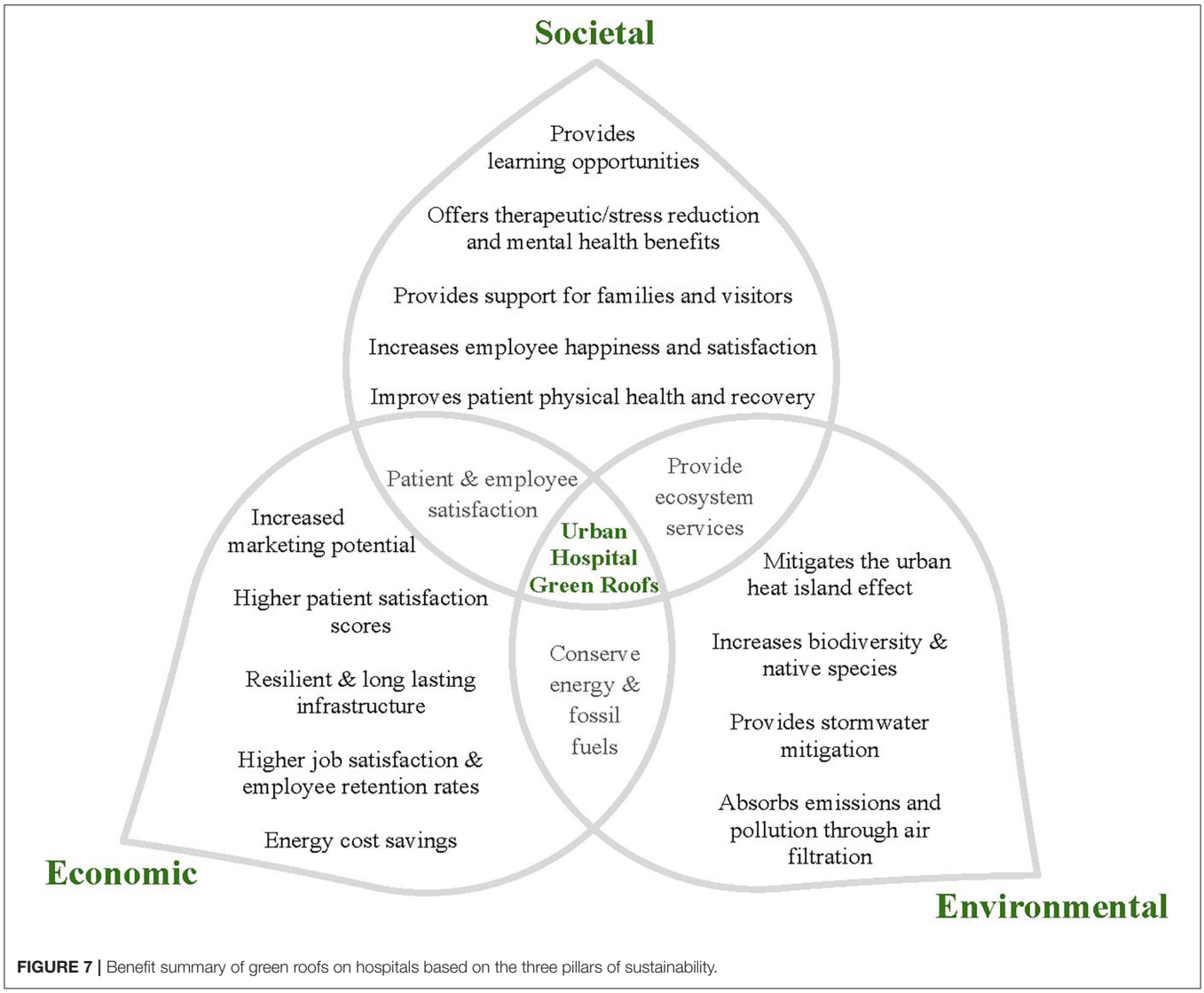

FIGURE 7 | Benefit summary of green roofs on hospitals based on the three pillars of sustainability.

present review suggests that hospitals can benefit by serving not only as a place of healing under the care of nurses and doctors, but also as a therapeutic experience for the body and soul to improve overall well-being and recovery rates. By incorporating these concepts back into modern medicine, overall patient, visitor, and employee satisfaction can increase (**Figure 7**). As urbanization and population density continues to grow, the inclusion of green infrastructures in the sustainable planning process of urban cities is necessary to mitigate the negative effects that reduced green space has on the environment, society, and the economy. The addition of native ecosystems in urban regions through the adaptation of green infrastructure supports resilience against climate change while providing the community with physical benefits of filtering pollutants to decrease illness rates and offering emotional support through the therapeutic relaxation properties of green space (Ulrich, 2002; Grunewald et al., 2019; **Figure 7**). Green roofs offer a solution for urban communities to become resilient in a climate crisis and support the health and wellbeing of the community while creating economic resiliency for the institution. By mimicking natural ecosystems and providing ecosystem services through green roofs, hospitals can offer support to the urban regions' native ecosystems; provide therapeutic benefits and improve the mental health of patients, visitors, and employees of the hospital; and provide direct and indirect monetary benefits to the hospital for expanding these services (**Figure 7**).

Modern medicine will need to make accommodations to their practices as urbanization and climate change continues to cause negative mental and physical effects associated with limited long and short term interactions with nature, contributing to nature deficit disorder, mental illness, and increased exposure to hazardous pollutants (Coutts and Hahn, 2015; Warber et al., 2015; Aerts et al., 2018). Similar to ancient physicians who prescribed garden walks to mentally ill patients, physicians have begun to incorporate green space

TABLE 3 | Cost-benefit comparison of the benefits green roofs offer hospitals vs. associated costs.

Three pillars of sustainability	Benefits (+)	Costs (–)
Environment	Biodiversity	No cost
	Stormwater mitigation	
	Urban heat island effects	
	Air filtration	
Society	Therapeutic qualities/stress reduction	No cost
	Family/visitor support	
	Employee happiness/satisfaction	
	Recovery rates	
	Learning opportunities	
Economy	Higher patient satisfaction	Replacement
	Employee retention rates	Maintenance
	Energy efficiency	Employment
	Greater infrastructure lifespan	Installation
Total	(+) 13	(–) 4

back into health care by prescribing nature walks to their patients for its therapeutic qualities (Warber et al., 2015; Leavell et al., 2019). Although green space is viewed as "desirable but non-essential," nature immersion is necessary to support healing in urban environments. Hospitals must shift their views on healthcare in order to successfully incorporate the holistic and therapeutic aspects of nature immersion for patients in urban hospital (Ulrich, 2002; Coutts and Hahn, 2015). Limited funding and research is delegated to projects involving green roofs on hospitals, but with the appropriate educational resources, hospitals can be awarded funding for these projects through grants and donations to avoid funding from operating budgets.

Based on a hospital's specific needs and wants, there are different considerations for their green roof and its components (**Table 4**). For example, an extensive roof would be better implemented on urban hospital roofs that offer viewing opportunities for their patients rather than a hands-on experience. However, if a hospital is interested in maximizing the ecosystem services from their green roof, they should heavily consider installing an intensive green roof. The decision to install an extensive or intensive green roof will certainly impact the cost of installation. Conversely, a pre-determined budget for the project may impact the type of green roof that a hospital can install, as well as the plants that will be grown there. Hospitals with existing roofs that cannot support the heavier infrastructure required for an intensive green roof or colder climates that restrict outside activity will still be able to benefit from extensive green roofs, similar to both the Metro Health University and Sharp Memorial Hospital (**Table 1**). While intensive green roofs require more maintenance and upkeep, the capacity for a larger number of plant species due to the greater depth of soil provides more garden space for patients, families, and employees to physically utilize the space. Newer hospitals or hospitals with the ability to sustain heavier roof infrastructure such as the John Theurer Cancer Center at HUMC can create larger ecosystems to support native species and offer an interactive experience for the community that may otherwise lack contact with nature because they are in urban settings. During the planning process, hospitals can choose to use a combination of both intensive and extensive green roofs, like Fletcher Allen Hospital. Regardless of the type of green roof built, they can undoubtedly provide benefits beyond what each of these examples identified at their own hospitals. Each of the hospitals had various motivations for building their green roofs, which ultimately impacts the final design and the benefits accrued to the green roofs. The research articles outlined in this review, however, highlight the many environmental, societal, and economic benefits the hospitals are also able to obtain beyond those originally considered.

Minimal scientific research has been done on the environmental, societal, and economic development of hospital green roofs in urban regions largely in part because many hospitals have not allocated the time or resources toward building these structures. The review of current research articles here allows for consideration of the benefits of green roofs to help hospitals examine the potential for implementation of green roofs on their own buildings. Education and funding for green roof development on hospitals needs to be put in place for health care decision makers to be able implement these changes. The future and the resilience of healthcare is going to rely heavily on innovative ways to offer environmental solutions to address the climate crisis in growing cities while simultaneously sustaining patient satisfaction and providing economic benefits.

CONCLUSION

Climate change and its effects on our environment and ourselves will continue to be the issue of our time. At the same time, urban areas are becoming more populated and climate change-related illnesses are increasing (Rocque et al., 2021). Because of this, urban hospitals play a pivotal role in implementing solutions to this problem, one of which is increasing the amount of green infrastructure. Urban hospitals are key players in the addition of green infrastructure based on the removal of natural ecosystems associated with their commercial infrastructure, their ability to impact the entire community, and their need for 24-h energy input. To overcome the challenges posed by urban growth and increased infrastructure, and to continue providing important ecosystem functions, hospitals can construct green roofs on their hospitals. Green roofs on urban hospitals can not only provide significant environmental benefits; they can also simultaneously contribute to societal and economic gains. These benefits include climate mitigation and resiliency, improved physical health and emotional well-being, educational opportunities, marketing/PR potential, and direct cost savings. These benefits and their impacts have the ability to outweigh the initial costs. More research should be devoted to exploring successful project management and funding of green infrastructure projects in

TABLE 4 | Considerations for planning and designing a hospital green roof.

Topic area	Variable of interest	Impact/recommendations
Building age and structure	New/existing building, structural support	• Support structure of existing buildings may result in green roof needing to be extensive • If an intensive green roof is desired, will have to ensure adequate structural support is present • Must also consider the weight that can be supported with existing support
Budget	Amount of available funding	• For hospitals with a smaller budget, extensive green roofs may be a better option • For hospitals with a slightly larger budget, intensive green roofs have the ability to provide more benefits and may be a better option
Space	Amount of square footage available	• Size of the green roof will impact cost • Available space may impact the decision for the green roof to be physically or visually accessible • Space may impact selected plant types, type of green roof selected, and activities that can occur on green roof
Type of green roof	Extensive, intensive, or combination	• Type of green roof selected will impact costs, with intensive green roofs resulting in higher expenses • Type of green roof will impact what plant types can be selected for the roof and the required maintenance • Activities that can take place on a green roof and the received ecosystem services will most likely be dependent on type of green roof
Accessibility	Visually accessible, physically accessible, or both	• Physically accessible green roofs offer more societal benefits than visually accessible benefits • Physically accessible green roofs offer more opportunity for activities • Accessibility of green roofs may impact type of green roof selected and costs of the project
Intent	Climate mitigation and resiliency, physical and mental health, economics, etc.	• For hospitals focusing on climate mitigation and resiliency, consider installing an intensive green roof and focus specifically on plant types • For hospitals focusing on physical/mental health, consider installing a green roof that is both physically and visually accessible, also consider what plant types and activities will help to achieve goals • Intent of green roof will impact costs of the project and required maintenance
Activities	Activities to occur on green roof: walking/ exercise, gardening, education, socialization, etc.	• Selected activities will impact the costs of the project and required maintenance • For hospitals interested in any activities, green roof should most likely be physically accessible

hospitals, as well as investigating the benefits of different green roof specifics such as plant selection, non-vegetative features, and type of green roof. This will allow for expanded integration of healthcare and the human-nature connection and the many benefits that come from this. With the addition of green roofs, urban hospitals can balance the three pillars of sustainability, contributing to sustainable development of cities and resilient healthcare.

AUTHOR CONTRIBUTIONS

AO'H concept and content development, writing- original draft and preparation, writing- review and editing, and research. AM, HS, AS, and TM: writing- review and editing and research. AT: content development, writing- review and editing, and project supervision. All authors contributed to the article and approved the submitted version.

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