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URBAN GREEN INFRASTRUCTURE ENHANCING BIODIVERSITY AND CLIMATE RESILIENCE IN SMART CITIES

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ABSTRACT
Background: Urban Green Infrastructure (UGI) is critical to increasing biodiversity and climate resilience in smart cities. Through their rapid urbanization, there is a turning point to optimize the ecosystem services in which a better solving framework is to combine UGI with smart technologies to enhance sustainable urbanization. Nonetheless, the success of integrations relies on social and economic aspects and governing systems.
Goals: The paper dwells on whether UGI can help in promoting climate resiliency and biodiversity. It is also investigated which socioeconomic status and governance act as moderators of the link between UGI, smart technologies, as well as climate adaptation.
Methods: The study measures the difference of UGI on climate resilience (0.323) as well as social-economic status (0.393) using quantitative analysis. The efficiency of smart technologies in the management of UGI is evaluated, paying attention to the aspect of governance as a possible moderation factor.
Results: Results show that UGI contributes immensely to the climate resilience and the socioeconomic well-being. Nevertheless, the mediating position of policy and governance on effectiveness of smart technologies is not proven. The socioeconomic statuses precondition the reception of UGI gain by collective communities.
Conclusion: Planning of the UGI strategy to reduce the effects of the toxic sprawl, along with good governance and meaningful urban planning, are key to the utmost resilience and sustainability. A potential direction of future studies is a more in depth focus on governance mechanisms and an explicit moderation test.

Keywords: UGI, Climate Resilience, Biodiversity, Smart Technologies, Socioeconomic Status, Governance, Ecosystem Services.

Introduction:

Historical and Placement

Robotic Process Automation (RPA) and AI are making smart cities smarter to become an active step toward intelligent urban management and sustainability. Such technologies have helped make data-driven decisions more manageable, advance administrative processes, and improve service delivery . Under the Urban Green

Infrastructure (UGI) management, AI and RPA can be used to ensure the optimal utilization of the available resources, better environmental management practice, and increasing the resilience to climatic changes . By coupling the use of the Internet of Things (IoT) devices, AI and RPA can be used to gather and analyse data in real-time and therefore the adaptive behaviour of urban systems can be achieved. One of the functions that this integration may be especially useful in UGI control is predictive maintenance of green spaces, optimization of water supply in urban vegetation, and management of pollution. But it should also be mentioned that the use of AI and RPA in smart cities has privacy, data safety, and equity issues, which need thorough consideration to realize the appropriate and fair use . There is a need to take a holistic approach to the successful usage of AI and RPA to manage UGI in a smart city. This involves the development of a work partnership among the stakeholders, adoption of an innovation culture, and discussion of any risks of operation that might occur with AI-based systems . In doing so, urban centers can maximize the potential of such technologies to develop smarter, more resilient and sustainable cities with the capability to effectively manage and maintain its green infrastructure (Abuismail, Sun et al. 2024).

In urban green infrastructure (UGI), SM technologies are vital in observing and maximizing the performance of UGI, and as a result, data-driven decision-making (DM) is gaining and becoming more significant in development work and management of UGI. The transformation of the urban green spaces through mixing them with the latest technologies, including sensors, data analytics, and artificial intelligence, makes it possible to control them more efficiently and effectively. Intelligent transportation systems are integrated into the smart city planning which then collect data using sensors and AI in terms of vehicle movements patterns and any other related information (Mendes 2022). The methodology can be applied to UGI planning, whereby comparable technologies can be employed to regulate and streamline green spaces. Another example, devices with IOT can measure the moisture of the soil, the quality of air, and the health of the plant, to provide real-time optimization of irrêtation and care routine. Insights can be learned in terms of how DDDM has been devised to work in advanced manufacturing systems (AMS), and be extrapolated to guide UGI management. Among the critical success factors in the AMS needed to ensure DM success is building a competency human resource, establishing data-driven culture, and ensuring the top management support. All these are also significant in the successful execution of DDDM in the planning and maintenance of UGI (Mell and Scott 2023). Finally, the opportunities of using smart technologies related to the planning and maintenance of UGI can create considerable benefits in the area of performance and sustainability of the greenery in the urban environment. Through big data analytics, AI, and IoT devices, city designers and administrators can use a data-driven approach, optimize the deployment of resources, and improve the quality of the city green infrastructure, in general. Nevertheless, the successful implementation plan is a holistic one that integrates technical, organizational, and cultural aspects in order to achieve full potential of the data-driven decision-making benefits to UGI management (Cheshmehzangi, Zuo et al. 2025).

The use of participatory planning processes have gained greater prominence through the development of urban green infrastructure (UGI) and presents a potential mechanism through which the various complications of food systems sustainability, environmental sustainability, and urban planning can be solved. The purposes of these processes are to authenticize the decision-making process and make it more democratic, more legitimate, and more efficient in overcoming challenges associated with urban communities. By adopting the monitoring and evaluation of participatory planning processes (MEP) framework, the assessment of such processes is made in a comprehensive way and it comprises six key stages, which include: case description, clarification of a M&E viewpoint, identification of analytical variables, the elaboration of M&E procedures, data analysis, and publication of findings. Interestingly, its mode participatory is highly embraced; however, they may be a problem since they can yield imbalance and a lack of responsibility . Group learning has been found to be an outcome as well as a measure to gain agreement in participatory planning process indicating that it is important that empirical studies are designed to have strong internal and external validity (Khan, Jhariya et al. 2022). There is also a new opportunity to engage citizens in UGI governance since the digital communication tool e-tools, including place-based e-tools, can be used. Finally, stakeholder input, accountability, ecosystem services incorporated planning processes are the key factors to develop UGI development during participatory planning process. Participatory processes can assist the decision-maker by providing multi-objective optimization strategies that will assist in the creation of both green and dense cities. Urban living laboratories (ULLs) have become a popular platform in the co-creation processes and enable experimentation and evidence-based policy making. Valuing multifunctional green infrastructure and incorporating ecosystem services into small scale greening plans enable cities to cultivate creativity and localism, which may result into the greater transformation of the green infrastructure at the urban level (Yang, Chae et al. 2024).

The Green Infrastructure Resilience Framework (GRF) and the indicator-based framework of climate-resilient urban regions are designed to increase the urban resilience by means of green infrastructure planning. As Saqib et al. propose, by connecting the many themes, such as urban heat islands, stormwater runoff, thermal comfort, biodiversity conservation, carbon footprint minimization, urban agriculture, and human well-being, their GRF is a systematic approach to resilience development in cities . This framework welcomes the incorporation of green roof into adaptive planning to have sustainable and resilient societies. The indicator-based framework by Rayan et al. aims at preparing a broad and holistic framework of climate-resilient urban regions of northwest Pakistan. They determined that there were twenty-two urban green infrastructure (UGI) indicators of urban sustainability which fell within three broad categories: Extremely Important, Important, and Moderately Important. It is the framework that attempts to solidify the linkages between climate resilience strategies, green spaces, ecosystem functions, and human health and wellbeing . Both frameworks give preference to the role of green infrastructure in the resiliency planning of a city (Gelan and Girma 2022). The two, however, are different in the area of focus and the approaches taken. The GRF is focused on green roofs because of their nature-based approach, whereas the framework by Rayan et al. has a wider angle of UGI planning. Moreover, the indicator-based framework is more specific in classifying indicators by the degree of importance, which may be especially helpful when prioritizing actions can be limited in resource constrained setting. As a sum up, the two frameworks are conclusive in their contribution to understanding urban resilience planning using green infrastructure. Although the GRF has the advantage of a thematic framework that focuses on green roofs, the indicator-based framework needs to be more detailed in advanced UGI planning. Such frameworks are in complement and can provide the planners and policymakers with a variety of responses to increase urban resilience to the conditions of climate change and other environmental issues (Pinto, Inácio et al. 2023).

Problem Statement

Urbanization is one important factor that affects the ecosystems and led to climate change in a number of mechanisms. Urban sprawl has also influenced land-use changes that impact biodiversity, food production, and ecosystem services as the rate of urban sprawling rises . The process of urban development can expand into high-risk zones, which makes people more susceptible to climate threats especially in the case of the less developed countries. Urbanization introduces urban heat islands (UHI) and urban dry islands (UDI) and changes the local climate conditions. Human-induced modifications in climatic conditions can cause the phenological shift in spring to be higher by 9.6 days and in autumn by 6.63 days in urban regions than in the rural countryside. UDI, with a sharp drop in atmospheric humidity, is stronger in humid than in arid regions due to the specifics of the background climate in each case and the type of vegetation (Dizdaroglu 2022). Urban climate changes may cascade into the ecological processes of these ecosystems and biodiversity. To sum up, urbanization is posing complex problems to ecosystems and human well-being; it interacts with climate change. Urbanization coupled with climate change is projected to lead to more megacity inhabitants being exposed to extreme warming heat, with 78 percent of residents being at risk of warming of 2.5 o C by 2050s in the worst-case scenario of climate change. The ecological effects of urbanization can be reduced with the help of sustainable planning, including infill development and climate-adaptive planning to save the ecosystem services . Urban development of the future should focus on fallibility to the climate, sustainable land governance, and the incorporation of effective land use policy as the keys to centrally diminishing disposable and enhancing environmental sustainability (Costadone and Vierikko 2023).

The significance of the Study

The consequences of sustainable urban planning and smart city evolution are big ones on the global scale. It is essential to combine the elements of technology, governance, and the principles of sustainability to develop the urban environment livable and efficient and eco-friendly. Initiatives of smart cities can fuel the clean energy growth, especially those located in coastal, big, and those based on resources, hence, achieving reduced energy security and sustainable development. Nevertheless, smart city projects are difficult to implement. The problem with data security, authentication, unauthorized access to the computer, and vulnerability at the device level should be solved. Moreover, the initiatives of smart cities lack the consistent indicators, database, and methodologies to evaluate, fund, and apply to them (Sharma, Hussain et al. 2024). The issue of social sustainability is something that is frequently ignored, and to avoid that, a holistic process should be introduced that will take into account links between people and places. In order to develop smart cities sustainably, urban planners and policymakers are urged to think over opinions of locals and other critical factors when designing and planning developmental projects . It is important to focus on the enhancement of urban infrastructure systematically instead of focusing only on the supply of technical products to end-users . Their success depends on collaborations of various stakeholders, inclusive decision-making, sustainable environmental activity, and fair economic growth . Moreover, information management is critical to support smart and sustainable urban development solutions with particular attention to risks and challenges. Cities can respond to those identified challenges by operating under these principles and making a step in the direction of the more prosperous, more equal, more sustainable future (Sharma, Hussain et al. 2024).

Research Objectives

The green infrastructure in cities (UGI) has been an essential element in augmenting biodiversity and climate resilience in smart cities. UGI enhances urban ecosystem activities, safeguards human health and welfare and mitigate the significant challenges of urbanization . It helps to conserve biodiversity through the establishment of habitats networks and biocultural diversity in multicultural cities. Remarkably, even though UGI has generally been regarded as the provider of ecosystem services, the application of the biodiversity-led approach and multifunctionality are needed to maximize the benefits that UGI can provide. There are those studies that have discovered that, the nature of the UGI chosen and how it is managed significantly affects carbon uptake and ecological balance in total. It emphasizes the role of context-sensitive creation of UGI that work with varying demands and cultural practices. In order to provide UGI integration, the policy frameworks must consider elaborating well-rounded and integrative indicator-based models of climate-resilient urban planning . It is important that cities put into consideration the advantages of the ecosystem services to adapt to climate change as well as incorporating climate change in other sectors . It is important to enhance the effectiveness of strategic planning and collaborative governance of UGI, at least in cities of the Global South . Furthermore, the assessments of multifunctionality can be improved with the use of tools, like public participation GIS, (PPGIS), and the performance-based monitoring (Hunt, Maher et al. 2022).

Research Questions

RQ1: In what way does UGI promote urban biodiversity?

What can UGI do to create climate resilience within smart cities?

How to best optimize UGI benefits under which strategies and policies?

2. Literature Review

What is UGI?

Urban Green Infrastructure (herein referred to as UGI) is strategically planned networks of green and blue structures in towns and cities that perform a broad palette of ecosystem services and contributes to human health, well-being, urban sustainability, and climate resilience . It covers ideas like urban greening, urban forestry and urban agriculture and seeks to create multifunctional greenspace systems in order to respond to the key issues of urbanization . One of the functions of smart cities that UGI cannot be absent in is how it supports increased resilience to environmental hazards, and enhances the functioning of urban ecosystems. It helps to achieve the sustainability targets, reduce climate influence, and generate numerous urban ecosystem services (Moazzem, Bhuiyan et al. 2024). The UGI is especially relevant to issues like the problem of overheating or flooding, air pollution, and loss of biodiversity, as well as a move toward social cohesion and green economic transition . Therefore, there is a strong contribution of UGI to biodiversity and climate resilience. The application of a biodiversity-based strategy to the development of UGI designs also adds to the operability and downtown resilience of cities, which has flexibility to address regionally specific issue. UGI activities are useful in working towards climate change reduction including the role of the urban forests and agriculture in reducing CO_2 . In addition, UGI can serve as a steppingstone between policy agendas focused on carbon neutrality, biodiversity levels, and human welfare that can guide cities on their path to being sustainable . Finally, it is important to note that UGI is an essential constituent of smart, sustainable cities that will have a multidimensional contribution to biodiversity preservation and climate resilience. Its insertion in urban planning and management needs to be holistic with environmental, social, and economic facets addressed to ensure that it can achieve its full potential with regard to improving the challenges of urban issues (Mertens, Stiles et al. 2022).

Urban green infrastructure (UGI) includes several components including street trees, parks, green roofs, green facades and blue infrastructure (refers to water bodies). These components offer a variety of ecosystem services and support urban sustainability and resilience to the climate. Multifunctionality of UGI is one of the most important aspects of the concept providing urban regions with ecological, social, and economic values. In addition, UGI elements can have several purposes at the same time to regulate climate and provide carbon sequestration, water management, and reduction of air pollution as well as mitigation of noise and protection of culture. An example would be that city parks could be used to offer recreational places alongside the aspects of biodiversity preservation and managing stormwater (Davies and Santo-Tomás Muro 2024). UGI is multifunctional and can also be applied to peri-urban agricultural landscapes that can be untilized within the UGI network to increase ecosystem services sustainably across scales. Introduction of UGI in urban planning and development involves some strategic consideration based on the situation of each city. In places like the Global South, implementing UGI presents some distinct issues due to the lack of infra-structures and informal settlements . To address those concerns, such a methodology as an evaluation of the potential of the retrofitted and multifunctional UGI implementation in the public space has been established (Bellezoni, Seto et al. 2022).

This is done by a study of site and setting of a design criterion, research on multifunctionality levels and evaluation of spaces that can be suitable in locating UGI. It is possible to make the integration of UGI within the urban planning even more effective with the help of innovation tools and methods. It is demonstrated that PPGIS has the potential to enhance the evaluation of cultural ecosystem services and aid UGI planning at multiple spatial levels (Herath, Fujino et al. 2023). Besides, the spatial organization of the urban blue and green infrastructure can be optimized with the help of planning support tools for the layout of integral optimization. A hybrid approach with UGI as the dominant element in a habitat services approach which pays attention to the local context is the best way to optimize the benefits of UGI. Summing up, effective introduction of UGI into urban planning and development should be an integrated process that takes into account the complexity of the elements of UGI, its multifunctionality, and, last but not least, the peculiarities of the urban setting. The possibilities to embrace the potential of UGI to overcome the challenges of urbanization and promote the quality of the lives of city dwellers thanks to context-sensitive strategies and the use of innovative tools is open to cities (Macamo 2022).

Biodiversity in Urban Environments

Urban green infrastructure (UGI) is an important aspect that contributes to the level of biodiversity in an urban ecosystem. The diverse varieties of vegetations and animals that UGI can support can contribute to the ecological well-being of cities, in general . The significance of biodiversity in cities is also gaining prominence, not just because of its inherent values, but also due to the various ecosystem services it offers to people residing in cities such as enhanced air quality, climate control over temperatures, and personal well-being. Interestingly, the urban setting can be highly diverse enough, in some cases, to even host endangered species. Nevertheless, not all the urban ecosystems have the same capability of sustaining biodiversity (Ahn and Juraev 2023). Natural remnants may be particularly important in supporting persistence of species of conservation concern, and novel ecosystems too can become increasingly relevant as they develop over time . This shows how the status of populations of species and the novelty of urban ecosystems should be taken into account in the planning of conservation strategies. There are multiple approaches to this sort of biodiversity promotion UGI design. These comprise:

1. Our approach was biodiversity based, taking into account habitat services and multifunctional view (Ruiz-Apilánez, Ormaetxea et al. 2023).
2. Multifaceted environmental, social, and biodiversity goals are optimized, so that most features of habitat quality and ecosystem services could be supported (Bellezoni, Seto et al. 2022).
3. Designing the integration of the locally contextualized biodiversity-led UGI approach into the planning and policy realms (Lapão, Correia et al. 2023).
4. The development of strategic habitat stepping stones within urban and peri-urban regions to improve connectivity of the overall habitat (Islam 2025).
5. The local and landscape features are taken into account in a multiscale considering especially the management of bird species (Sarfo, Bi et al. 2023).
6. The strategy is to design UGI to benefit food sources of ground-dwelling animals with an emphasis on native plants (Valente, Marinelli et al. 2022).
7. The diversity of ecosystem services and biodiversity is supported when balancing tree cover in parks and brownfields .
8. There should also be the creation of green space networks with the aim of making it more connected and maintaining its biodiversity through processes like the least-cost path and graph theory (Bhattacharya and Mukherjee 2025).
9. The development of context-sensitive approaches symmetrically responds to the interests of different needs and cultural practices of urban dwellers interacting with nature.

Through these measures, cities will be able to contribute more to biodiversity conservation, at the same time making the life of urban dwellers more pleasant.

Urban threats and biodiversity loss Urban biodiversity is prone to threats to a great extent, including habitat loss or destruction. There are several factors that may cause these threats or inhibit these threats to the urban biodiversity, which require some insight (Wang 2023).

Deforestation and conversion of land to other purposes such as city development exposes biodiversity to great threats. Urban areas are associated with immense loss of natural habitat, which poses a hazard to biodiversity and social economic sustainability. As illustrated in China, due to the rapid growth in urbanization between 1992 and 2012, a large proportion of the natural habitats was destroyed whereby the Pearl River Delta lost 25.79 per cent of its natural habitat and the wetlands in the area lost 41.99 per cent. Interestingly, the urbanization phenomenon does not always cause loss of habitat since rivers within cities may be preserved or created with respect to its role in draining the water, which may be an ecologically significant corridor (Hanna, White et al. 2023). Nonetheless, these urban rivers are subject to the anthropogenic pressures common in cities, including built-up and road networks and the presence of water pollution that influence the quality of the habitat in river corridors . In order to overcome these problems, conservation planners need to find ways to focus and prioritize the protection of priority habitats, especially the ones within rapidly changing urban areas, before they are destroyed. Green and blue spaces in cities (UGBS) are essential to conserving biodiversity, and yet their efficacy is influenced by size, location, exposure to threats, among others. High urban wildness and quality habitat positive correlation with biodiversity is linked to large peripheral UGBS. Conversely, smaller centrally positioned UGBS are more susceptible to the threats and less efficient in aiding urban biodiversity. Urban biodiversity should be supported by improvements of habitat quality in larger-centric UGBS strains using rewilding approaches and mitigating exposure to threats (Jezzini, Assaf et al. 2023).

Climate Resilience in Smart Cities

Green infrastructure in urban cities (UGI) is critical in the approach of both climate change adaptation and mitigation. The proper combination of urban greening with green walls and green roofs, urban parks, and street trees, in the form of UGI, displays various advantages in addressing the challenges related to climate change . These green features contribute to curb the urban heat island effect, minimize the flood hazard, and enhance the resilience to climate change consequences in general in terms of urban areas . In numerous works, UGI was proved to be very efficient in climate resilience. As an example, the study made it possible to conclude that trees reduce the values of Physiological Equivalent Temperature (PET) in the afternoon by an average of 13% compared to existing vegetation, and green facades compensate the effects of 5-10% (Hanna, Bruno et al. 2024).

Moreover, UGI could be involved in the process of stormwater handling and mitigation of floods and especially in regions experiencing higher precipitation due to climate change. Interestingly, the capacity of UGI to maintain climate resilience will not be fully reliant on the amount of green cover but rather spend through tactical positioning. It is preferable to put vegetation where it will be exposed to heat instead of having a high proportion of green cover (Sheng, Ozgun et al. 2023). More than that, incorporation of blue-green infrastructure (BGI) into coastal cities has proven to be effective in facing risks associated with climate change, including floods and sea-level rise . Altogether, UGI is an important sustainable measure that can combine both adapting to climate change and mitigation in the battle against it . With the inclusion of UGI in cities planning and design, urban areas will be more resistant to the effects of climate change, but at the same time contribute to biodiversity, human health, and well-being . With the challenges that climate change has imposed so far, the use of UGI is proving even more pivotal in making climatic environments within the cities friendlier (Oliveira, Santagata et al. 2022).

Urban heat islands (UHI) and stormwater constitute an important issue in any urban area in the world and they have sweeping impacts on carbon sequestration and air quality. Green stormwater infrastructure and nature-based solutions (NBS) have become an efficient approach to solve these problems and offer a variety of ecosystems. Green roofs, rain gardens, bioretention basins, and vegetated swales are types of vegetated water-sensitive urban design (WSUD) technologies that have been used successfully to reduce the UHI effects and to manage stormwater . Such systems not only fulfill their main role of hydrology and water quality but also play a role in carbon trapping. An example is rain gardens as they have proven to have a supreme potential to sequester carbon offsetting their overall carbon footprint (Jha, Joy et al. 2024). Between 45 and 70 percent of their carbon footprints are mitigated as a result of the use of other WSUD technologies through sequestratio. Interestingly, the success of water bodies in the lowering of temperatures is always determined by water size, its shape, the surrounding land cover, climate and vegetation . Water bodies on green spaces increase cooling with evapotranspiration and shading and helps further mitigate UHI and improve the air quality. To conclude, the green stormwater infrastructure and NBS provide a multi-dimensional solution to solving environmental issues in the city. The solutions also control stormwater, alleviate the impact of UHI, reduce carbon emission and enhance air quality. These strategies must be taken into account by urban planners and policy makers as a part of sustainable urban development because of the possibilities of developing more resilient and ecofriendly cities (Jha, Joy et al. 2024).

The role of UGI in reducing extreme weather Causes of extreme weather events

Urban green infrastructure (UGI) offers many ecosystem services which have benefits to human health and the environment. These services cannot be within reach unless in the quantification of these services, practice has been used to grasp their economical and environmental worth. Studies indicate that as far as UGI is concerned, it creates significant economic values in the city. As an example, in the capital core area of Beijing, it is estimated that the overall economic value of ecosystem services which are offered by UGI is about CNY 1.56 billion (USD 240 million) annually or CNY 91.76 (USD 14) per head resident. The highest share (46.32%) was based on carbon sequestration and generation of oxygen. Other services quantified are climate, water control and conservation, reduction of air pollution, reducing noise, and cultural services. Cities and urban regions may differ considerably in their access to ecosystem services the quantity and distribution of these services (Lapão, Correia et al. 2023). Comparison of five cities located in four continents revealed that although all cities had rather similar overall proportions of UGI (35-50% of the urban footprint), they substantially varied in the volume of provided services. As an example, aggregate cooling was 0.44 o C in Leicester and 0.98 o C in Medellin, and pollution removal was 488 kg PM2.5/yr in Zomba and 48,400 kg PM2.5/yr in Dhaka. To end with, although UGI can offer a range of advantages to groups and individuals living in cities, the number of firmly established ecosystem services and their utility may considerably differ in terms of their number and capacity, depending on the local settings and conditions, choices of species, and management decisions. That is why context-specific evaluation and development-specified UGI strategies may help to maximize the delivery of ecosystem services in various urban environments (Ravagnan, Rossi et al. 2022).

Urban green infrastructure (UGI) has many health and well-being, economic and social opportunities. The UGI spaces portrayed as socially benefiting affect a lot the motivation people have to visit such spaces. The results of the study conducted in Southeast Nigeria revealed that the primary purpose of the visits of UGI spaces was associated with the enjoyment of nature and fresh air, relaxation, and walking (Islam 2025). The highest social advantages were the facilitation of human-nature interaction, increased life satisfaction, and easy socialization. Also, UGI is vital in the innovation of physical health, social networks, and a community feel. Interestingly, their distribution in UGI is also greater in most cities possibly creating disparities with regard to their access and advantages (Rehman, Aziz et al. 2023).

According to one report conducted in Bradford, UK, the higher the number of street trees in the neighbourhood, the greater the proportion of Asian/Asian British and the lower the socio-economic status, whereas better access to community-managed greenspaces was linked to high-income and predominantly white household living in neighborhood. This is an indication of why causal factors of disproportionate distributions of UGI should be understood in order to support an equitable access and provide optimal public health consequences (Sarfo, Bi et al. 2023). Finally, the main economic, social benefits of UGI high-level mobility are the enhancement of both physical and mental health, socializing, and an overall feeling of life satisfaction. Nonetheless, to attain the totality of these gains it is very essential to make an equitable allocation of UGI in accordance to the requirements of target groups. The explanation of what publicly motivated people to visit UGI spaces, as well as the variables that can predict the visitation, is critical to policy-making, planning, and management of urban green infrastructure (Bona, Silva-Afonso et al. 2022).

There are many barriers and challenges to implementation of urban green infrastructure (UGI) in smart cities, and need to bring innovative solutions to overcome the barriers. Interdisciplinary research and collaboration are found to be essential to remedy these issues as it is pointed out by multiple researchers in the literature. Weak instrumental support of the UGI planning is one of the key issues, as well as systemic and procedural barriers. This implies the presence of the necessity to establish more powerful policy frameworks, and better planning processes. Also, there exist no appropriate ways to manage the complex networks of actors whose interests are conflicting and identify the design and operational choices of the systems across different features and time scales. Interdisciplinary research is fundamental so as to respond to such challenges (Capari, Wilfing et al. 2022).

To solve the technical problems of energy system integration in smart cities, the implementation of computational intelligence, including sensors and built-in algorithms, can be helpful . Moreover, the implementation of Quadruple Helix Model and changes to a sociotechnical framework could help to achieve successful cooperation among the different stakeholders who would help to offer sustainable and inclusive smart cities. Finally, the areas that demand future work in terms of the UGI implementation in smart cities should be dedicated to the elaboration of the participatory integrated models that apply the bottom-up actions and involve stakeholders (Zaręba, Krzemińska et al. 2022).

Multidisciplinary models of research and training remain relevant to the current demands of the students in higher education and can help train students to tackle non-linear urban issues . With approaches of policy learning and integration of scientific knowledge with defining community-based needs and articulating urban environmental goals, researchers can show how the adaptive governance and nature-based solutions can be strategically implemented within cities based on the UGI (Capari, Wilfing et al. 2022).

The treatment of upper gastrointestinal (UGI) pathologies is rapidly changing, and there are some trends and topics on which it is possible to work in the future. There is variation in approach, but endoscopic techniques are increasingly sophisticated to treat UGI anastomotic leaks. Among the techniques used are fully covered self-expandable metal stents, endoscopic vacuum therapy, and endoscopic internal drainage, however, these treatments are suboptimal and require additional studies to establish evidence-based protocol. The treatment of UGI bleeding is centered on endoscopic therapy with recent success in terms of multimodal treatment in complex cases. A curious contradiction is that even as endoscopy is evolving into an advanced field there is also increasing realization that quality control should not be just technical (Shafik 2024).

The next steps can be performed toward the standardization of quality indicators of the overall patient experience, including the pre-procedure evaluation and follow-up . Moreover, knowledge on UGI symptoms in a particular patient population, e.g., diabetics, is becoming more widely known and this could make screening and management more specific . To conclude, the persistent tendencies in the UGI management regarding the future are the tendency towards standardizing endoscopic procedures and quality control measures, consideration of a more individual approach based on the features of patients and risk factors they face. This direction of research must be continued to build up evidence-based protocols and assess the long-term consequences of introducing the new treatment interventions (Szpilko, Fernando et al. 2024).

Green infrastructure in cities (UGI) is vital in increasing the biodiversity and climate resilience of urban areas. UGI enhances the functioning of urban ecosystems, safeguards the health and well-being of humans and leads to maintaining a sustainable environment . It can be used as a pillar of countervailing and mediating the twofold emergency of anthropogenic climatic change and human health degradation. Planning, design and delivery of UGI can act to simultaneously reduce and withstand climate change, serve human health and well-being, and boost biodiversity. Nevertheless, it involves cross-scale decisions and synergies and trade-offs across climate resilience, biodiversity and well-being of people goals (Rath and Mohapatra 2023).

Interestingly, the biocultural diversity concept offers novel understanding of human-nature relationships in multicultural urban societies demanding a more context-sensitive UGI development that is sensitive to a variety of cultural practices . Finally, UGI has proved to be able to contribute to the sustainable and resilient urbanization significantly. This may minimise the impacts of climate change, increase resilience, and create cities with sustainability. Besides, UGI is also essential to establish thermally resilient communities through the mitigation of undesirable climate change occurrences and the increase in thermal resilience on various spatial scales . By putting the concept of biodiversity-led UGI design into planning and policy dimensions, one contributes to increasing the functioning and the resilience of its cities and offers flexibility to address the local issues, including overheating, flooding, air pollution, health and wellbeing, and loss of biodiversity (D'Onofrio, Camaioni et al. 2023).

The concept of urban green infrastructure (UGI) has been useful in guiding and development of smart cities because urban green infrastructure provides multiple benefits to a city and city dwellers. The use of UGI in smart cities will be a critical element of improving the quality of life and making cities more sustainable and able to overcome different urban problems . The UGI planning focuses on the creation of multifunctional networks of green and blue spaces able to provide a variety of ecosystem services. It can not only contribute to a significant increase in air quality, including those situations when space is limited, but also to lifestyle and health improvements of residents . Another reason why the importance of UGI is of great significance is that it can solve the key issues of urbanization: increase social aggregation, contribute to the development of a green economy, adapt to climate change, and preserve biodiversity (Andersson, Grimm et al. 2022).

Curiously enough, the incorporation of UGI in smart city planning presupposes the shift in the paradigm of city green space planning, moving towards the more comprehensive one. This includes accessing more high-quality information on more diverse ecosystem services and more spatiographically specific social valuation approaches, including the use of public participation GIS (PPGIS) (Valente, Marinelli et al. 2022). Also, the notion of the biocultural diversity brought additional understanding to human-nature interactions in multicultural urban communities, where context-sensitive development of UGI is necessary to account various cultural practices and needs. To sum it up, it is essential to bring UGI to the development and planning of smart cities to develop sustainable, resilient, and livable cities. It does not just augment the materiality of cities, but also helps generate social harmony, and economic development. Since the development of smart cities does not seem to be stopped, the integration of UGI will become essential when dealing with urban challenges and bettering the overall quality of life of residents (Frantzeskaki, Ossola et al. 2022).

The Multi-Tool Solution of UGI

Air quality and water management benefits, and health gains Moderate to severe air quality benefits Overall benefits Moderate to severe water management gains and public health gains The land of Urban Green Infrastructure (UGI) is a multipurpose measure that presents a vast number of air quality, water management, and the health of people benefits in cities. The purpose of UGI planning consists of creating green and blue space networks to provide multiple ecosystem services and enhance city life quality (Bhattacharya and Mukherjee 2025). These multifunctional networks are able to deliver ecological and social advantages and at the same time deal with a range of town issues . UGI is highly significant in the cleaning up of the atmosphere pollutants. In Italy, as an example, in the Municipality of Ferrara, the effect of the UGI was to collect about 19.8 Mg of PM10 and 8.6 Mg of O3 in 2019 and translated to substantial economic cost savings . In the Metropolitan City of Naples, 36 million euros per year are extracted by the UGI and about 1,148 Mg of PM10 . Water management is also provided by UGI as it minimizes runoff on the surface, and its efficiency is expected to reach 34% in some instances . Multifunctionality of UGI does not only have environmental advantages, but also has beneficial implications to the society in terms of health and its social background. UGI can contribute to the enhancement of human health and well-being due to the provision of recreational space, noise pollution, and super-livability of a city . These ecosystem services may have a high economic value as has been seen in Beijing where UGI provides CNY 1.56 billion each year . It is notable, though, that depending on the type of urban form, the effectiveness of UGI cannot always be the same and planning and adopting UGI needs to be in a context-specific manner (Wang 2023).

Carbon sequestration and heat island mitigation

Carbon sequestration and urban heat island (UHI) mitigation are two related strategies, the joint implementation of which can play a key role in adapting urban regions to climate change and reducing mitigation loads. Vertical Greenery Systems (VGS) have transformed since the ancient days to contemporary city farms signifying their importance in reducing the effects of global climate change in cities through carbon sequestration . The result is, however, condition-specific with carbon sequestration in some factors, including urban heat island effect and seasons. Remarkably, studies have revealed that amplified warming due to UHI potentially has ramifications of limiting carbon sequestration in vegetation during hot seasons and leading to vegetation growth during cool season (Hanna, White et al. 2023). Such a phenomenon renders a complicated correlation between UHI and carbon sequestration and the sedimentation trend of carbon storage in sub-tropical cities is spring> summer >autumn> winter. Also, the potential of small urban parks in encouraging urban resilience has been listed among the possible resolutions by providing the following benefits, carbon sequestration, the curbing of UHI, and enhanced stormwater control . To sum up, green infrastructure, cool pavement, cool roof, and other effective UHI reduction measures have the potential to increase the carbon sequestration level in combination with tackling climate change at the same time (Jezzini, Assaf et al. 2023). Nature-based solutions, including street trees in urban canyons have the potential of cooling areas significantly and its cooling effect co-benefit is highest when combined with carbon sequestration. Because cities, becoming more exposed to the effects of climate change, should look into the way to mitigate their impact by incorporating carbon sequestration and reduction of the UHI effect on cities, using a green infrastructure and city planning is a central approach to developing sustainable urban communities and resilient cities (Hanna, Bruno et al. 2024).

Strategies and guidelines on implementation of UGI

Case studies and world best practices

Urban green infrastructure (UGI) has become an increasingly popular form of sustainability and resiliency intervention in cities as a way to improve urban quality of life. The approaches and problems that the UGI implementation policy and strategies observe to be different in the Global South and Global North. Due to climate change and the need to promote sustainability, cities in the European Union are growing their UGI . A project in Lugo, Spain, showed that urban forests and agriculture measures had the potential to mitigate climate change with an ecological balance of 1,85 Global hectares in the EU LIFE Program . Carbon uptake was however quite low as compared to other cities in Europe and this will require context specific measures. In Europe, strategic greenspace planning is evolving towards UGI compliance in regard to network connectivity and restoration gap accompanies it in the scope and level of consideration . Interestingly, the Global South is much different in terms of challenge and opportunity in relation to UGI implementation. The latent competence of slum dwellers in UGI is a community resilience and a source of action in the form of trickle-up development in the precarious urban environment in Bangladesh. This underscores the need to tap local knowledge and participatory planning of UGI (Oliveira, Santagata et al. 2022). The proposed model of indicator-based comprehensive framework has been developed in Pakistan to develop climate-resilient urban regions and considers the necessity of context-specific solutions . To sum up, UGI implementation necessitates a complex approach to the local community and policy integration and even stakeholder involvement. Whereas the Global North aims to increase the current UGI, the Global South frequently has to deal with the concerns of the fundamental infrastructure and developing UGI. The effectiveness of regional UGI implementation should be assured by policy monitoring, evaluation and capacity building of strategic planning and collaborative governance across regions . Future studies must be aimed toward formulating comprehensive methods that leap-frog the boundaries between sectors and facilitating environmental justice, especially in the Global South (Sheng, Ozgun et al. 2023).

Hypotheses:

H1: Urban Green Infrastructure (UGI) has a beneficial influence on Climate Resilience in smart cities (Bona, Silva-Afonso et al. 2022).

H2: Smart Technologies of UGI Management is positively imposing an impact on Climate Resilience to smart cities (Capari, Wilfing et al. 2022).

H3: Urban Green Infrastructure (UGI) has a positive role to play in smart cities Ecosystem Services(Capari, Wilfing et al. 2022).

H4: Ecosystem Services is impacted positively by Smart Technologies in UGI Management in smart cities (Pedersen Zari, MacKinnon et al. 2022).

H5: Climate Resilience in smart cities is strengthened by Ecosystem Services (Zaręba, Krzemińska et al. 2022).
H6: The interconnection between Urban Green Infrastructure (UGI) and the Climate Resilience is mediated by Ecosystem Services (Rehman, Aziz et al. 2023).
H7: Climate Resilience is mediated by Ecosystem Services between Smart Technologies to manage UGI and Climate Resilience (Ravagnan, Rossi et al. 2022).
H8: Socioeconomic Status of Communities has influence on linkage between Urban Green Infrastructure (UGI) and Climate Resilience intensifying or decreasing the effect (Jha, Joy et al. 2024).
H9: The relationship between Smart Technologies to UGI Management and Climate Resilience may be moderated by relevant Policy and Governance Frameworks hence affecting their effectiveness (Jha, Joy et al. 2024).

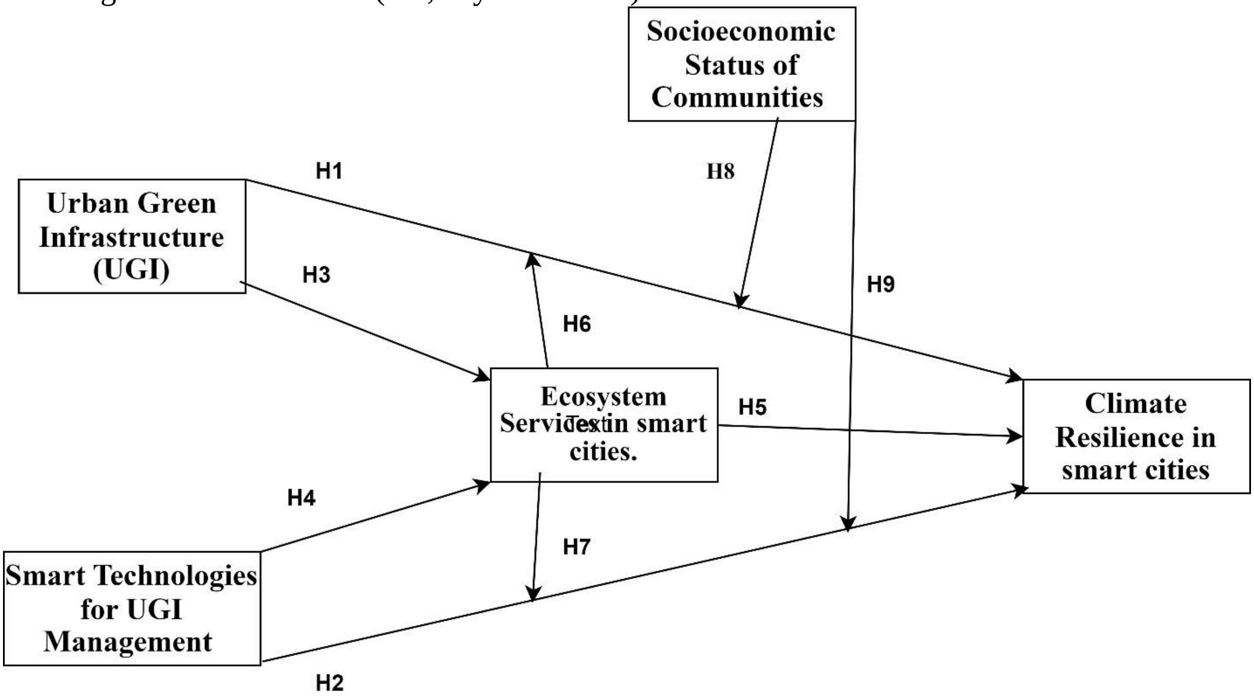

Figure 1: Proposed Research Model

3-Research Methodology

Research Design: Quantitative Approaches

The research design adopted in this work was quantitative research design, which examined how Urban Green Infrastructure (UGI) can influence the climate and biodiversity resilience in smart cities, and in particular in Pakistan. The empirical study has a structured methodology that will also be used to assess the contribution of UGI towards urban sustainability especially the ecosystem services and smart technologies, in an objective manner. This study uses structured surveys, statistical modelling and analysis of the environment data to make evidence-based suggestions to policy makers and urban planners. Such quantitatively oriented research can be generalized to other smart cities and make the results reliable (Szpilko, Fernando et al. 2024).

In this study, the focus of the researchers is on important smart cities in Pakistan where UGI is under implementation or planned to be implemented in the form of sustainable urban development. These cities were Islamabad, Lahore, Karachi, Peshawar, and Multan that all have existing projects related to the Green areas, smart planning of cities, and environmental sustainability. The 534 respondents were sampled by using stratified random sampling technique in order to get a diversity of opinions. The respondents were the urban planners (120), environmental specialists (100), municipal officials (114), academicians (80) and residents (120). Such segmentation means that the data would be collected on the stakeholders of UGI projects who have participated directly in the projects or have been impacted by these projects (Shafik 2024).

In order to gather primary data, this research used structured survey adjustments that contained questions on a Likert-scale (1-5) to determine the perceptions of UGI effectiveness. The survey addressed major topics about UGI and climate resilience, smart technology effects in sustainability in cities, and whether or not there are ecosystem services addressed. Besides the survey answers, the secondary data in the form of GIS mapping, IoT-based environmental monitoring, and government reports were reviewed. Geospatial data will give information on how to control temperature, cope with the better quality of the air, and manage stormwater, which will be used to conduct a comparative study of the UGI performance in various urban environments (D'Onofrio, Camaioni et al. 2023).

In the analysis of the data, SPSS and AMOS programs were combined so as to have a strict analysis of the hypotheses. The descriptives of SPSS will be used to summarize the important trends and reliability, reliability, and validity testing will be achieved through the use of Cronbach alpha (0.7) and EFA. AMOS Structural Equation Modeling (SEM) was used to test the inter-relationships among variables. To ensure a sound model fit, the conceptual framework will be validated using Confirmatory Factor Analysis (CFA), where other indicators that the current model fits well include the chi-square/df ratio (< 3), Comparative Fit Index (CFI > 0.90), and Root Mean Square Error of Approximation (RMSEA < 0.08) (Rath and Mohapatra 2023).

The strength of the methodology notwithstanding, the study may be limited by the fact that there are data restrictions on some cities, by bias in self-reporting survey data, and by differences in smart-city policy. Nonetheless, these can be prevented by randomized sampling, the anonymity of responses and validation of multi-source data. All the ethical considerations and processes such as informed consent, confidentiality, and respecting the research criteria were adhered to (Andersson, Grimm et al. 2022).

Finally, the research design followed a stringent, quantitative research design in assessing the role of UGI in climate resilience in smart cities in Pakistan. This study offers policy-relevant information that policymakers, urban planners, and environmental stakeholders can use to jointly support the global effort in reaching clean air. The findings will be used in order to ensure sustainable urban development by focusing on urban resilience strategies, the opportunity of integrating green infrastructure, smarter technologies, and ecosystem services within the resilience strategy (Frantzeskaki, Ossola et al. 2022).

Variables Measurement

The variables included in the present study were measured in a structured manner assessing Urban Green Infrastructure (UGI), Climate Resilience, Ecosystem Services, Smart Technologies, and Moderating Factors through a Likert-scale survey (1 = Strongly Disagree to 5 = Strongly Agree) and secondarily validated data. UGI is determined by such indicators as the coverage of green space, the preservation of biodiversity, urban forestry programs, and climate resilience can be evaluated based on the regulation of temperature, mitigation of flooding, and enhancement of the quality of air by means of GIS and IoT-based environmental monitoring . The ecosystem services are considered as mediating variables and measured in accordance with the parameters of carbon sequestration, air purification, and recreational value . The assessment of smart technologies applied to UGI management is appraised as the AI-based environmental surveillance, IoT-aided irrigation, and the GIS-aided urban development in order to provide the evidence-based decision-making in the interest of sustainable urban environments. Also, the social-economic status (income, education, and access to infrastructure) and governance structures (implementation of policies and stakeholders involvement) can be examined as moderating factors affecting the UGI effectiveness . These constructs were confirmed to have reliability, validity in SPSS (Cronbach alpha, (alpha 0.7)) and Exploratory Factor Analysis (EFA) as well as confirmatory factor analysis (CFA) in AMOS with model fit indicators (CFI > 0.90, RMSEA < 0.08), and statistically sound results . This measurement framework gives an end-to-end data based assessment of UGI on biodiversity conservation in smart cities in Pakistan and climate resilience (Kataria, Rani et al. 2024).

Reliability and Validity

The reliability and validity statistics of five determinants in regard to the sustainable urban development, Smart Technologies and Management (STM), Climate Resilience in Smart Cities (CRS), Urban Green Infrastructure (UGI), Ecosystem Services (ES), and Socioeconomic Status of Communities (SSC), are illustrated in Table 1. The constructs have several items (not all items in this study were used), but with differing factor loadings based on the contribution that each item has to the construct. Internal consistency is supported as the coefficients of cronbach alpha (0.738-0.844) is greater than 0.7 suggested as a condition of reliability (Nunnally & Bernstein, 1994). On the same note, Composite Reliability (CR) values were__.07, which supports the strength of the constructs . The results support sufficient convergent validity, since the AVEs, 0.51-0.693, confirmed the values lying higher than 0.5, as stated by Fornell and Larcker (1981). The findings confirm the reliability and convergent validity of the measurement model that should be used to evaluate urban sustainability initiatives (Cousins 2024).

Table 1: Reliability and Validity

Variables	**Items**	**Loading**	**Cronbach Alpha**	**CR**	**AVE**
STM (Smart Technologies and Management)	STM1	0.60	0.840	0.840	0.693
	STM2	0.75			
	STM3	0.73			
	STM4	0.76			
	STM5	0.8			
	STM6	0.77			
	STM7	0.72			
CRS (Climate Resilience in Smart Cities)	CRS1	0.69	0.844	0.844	0.654
	CRS2	0.68			
	CRS3	0.81			
	CRS4	0.87			
	CRS5	0.74			
	CRS6	0.74			
UGI (Urban Green Infrastructure)	UGI1	0.71	0.769	0.769	0.55
	UGI2	0.67			
	UGI3	0.66			

	UGI4	0.65			
	UGI5	0.64			
	UGI6	0.61			
	ES1	0.54			
	ES2	0.46			
	ES3	0.56			
E**S** (Ecosystem Services)	ES4	0.55	0.748	0.748	0.51
	ES5	0.35			
	ES6	0.73			
	ES7	0.38			
	SSC1	0.43			
	SSC2	0.47			
	SSC3	0.48			
SSC (, **S**ocioeconomic status of Communities)	SSC4	0.52	0.738	0.738	0.51
	SSC5	0.55			
	SSC6	0.5			
	SSC7	0.49			

Model Fit

Table 2 reported model fit indices that showed that the measurement model fit well overall. Using CMIN= 721.448 degrees of freedom (DF) = 485, the CMIN/DF = 1.488, which is within the acceptable limits of the range of 1 to 3 and hence a good fit to the model (Kline, 2016). The recommended threshold of 0.95, the value of a Comparative Fit Index (CFI) was 0.957, which once again proved the proper fit of the model to the data. The result of the Standardized Root Mean Square Residual (SRMR) 0.043 was lower than the proposed 0.08, which confirmed the goodness of fit of the model . Besides, the Root Mean Square Error of Approximation (RMSEA) was extremely small (0.030), so it did not indicate model misspecification and was well within the acceptable limit (0.06) . The PClose of 1.000 that passed the 0.05 variance also confirms an excellent fit of the model by indicating that RMSEA is not significantly varying with 0. The obtained results indicate that the proposed measurement model is statistically sound and highly appropriate to evaluate the relationship between constructs.

Table 2: Model Fit

Measure	Estimate	Threshold	Interpretation
CMIN	721.448	--	--
DF	485	--	--
CMIN/DF	1.488	Between 1 and 3	Excellent
CFI	0.957	>0.95	Excellent
SUMMER	0.043	<0.08	Excellent
RMSEA	0.030	<0.06	Excellent
P Close	1.000	>0.05	Excellent

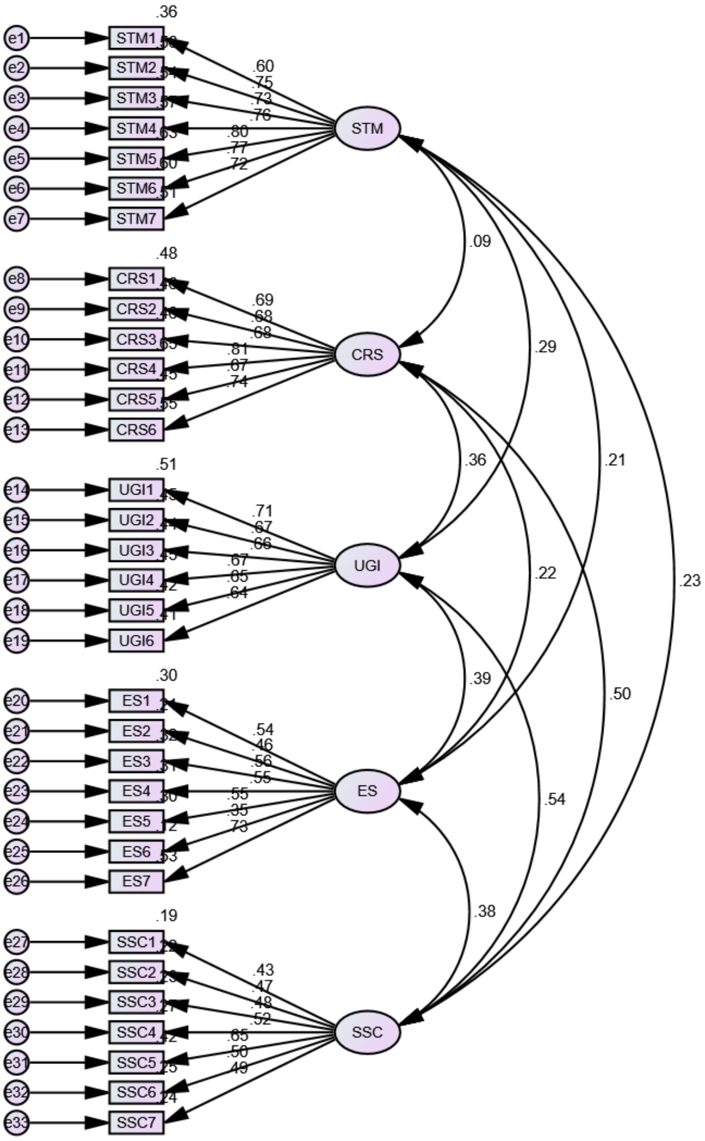

Figure 2: CFA of Model

Correlations of Variables:

As can be seen in the table, the standardized coefficients (or estimated correlations) between STM, CRS, UGI, ES, and SSC vary in power, with three of them being very weak (STM ↔ CRS: .094), and the rest strong (UGI ↔ SSC: .536). Through Cohen (1988) guidelines, their values can be estimated as weak (<0.20), moderate (0.20-0.50), strong (>) 0.50; strong coefficientsлів 실| py planet 9036 and SSC (.498) denotes high shared variance or structural ties, and a moderate correlation (e.g., UGI ↔ ES:.389) may signify theoretically significant relationships, whereas a weak effect (e.g., STM ↔ ES:.205) may still remain practically relevant Contextual factors, including how particular variables are defined (e.g., whether CRS can be understood as a measurement of cognitive resilience) and whether statistical significance or the sample size is reported , are important since interpretation of effect sizes depends on the field of research; in particular, a correlation of 0.50 might be a paradigm-shift in genetics, but a triple-redundant in psychometrics.

Table 3: Correlation of Variables

			Estimate
STM	<-->	CRS	.094
STM	<-->	UGI	.289
STM	<-->	ES	.205
STM	<-->	SSC	.230
CRS	<-->	UGI	.365
CRS	<-->	ES	.217
CRS	<-->	SSC	.498
UGI	<-->	ES	.389
UGI	<-->	SSC	.536
ES	<-->	SSC	.381

Hypotheses Results

H1: Urban Green Infrastructure (UGI) positively impacts Climate Resilience in smart cities.

This direct effect similarity between the UGI and Climate Resilience (CRS) is 0.174, which means moderate positive correlation exists between the two variables. This implies that the direct growth of UGI will contribute to greater Climate Resilience, probably as the result of enhanced environmental conditions, including heat, stormwater, and carbon sequestration. In spite of the indirect effect (which will be discussed in H6), the direct positive impact sustains the idea that the implementation of UGI contributes to the improvement of resilience of smart cities due to climate-related challenges (Cousins 2024).

H2: Smart Technologies in UGI Management have an impact and yield positively on Climate Resilience in smart cities.

The direct impact of Smart Technologies for UGI Management (STM) on Climate Resilience was -0.030, contrary to expectations, which shows the STM did not contribute to the Climate Resilience in a significant manner. This adverse effect albeit small is a possible tone that not a single tool is enough to enhance resilience, and that this may need other elements, e.g., good governance, good integration of an infrastructure, or community engagement, to work. This observation is inconsistent with H2, a finding that might indicate that STM cannot on its own contribute to Climate Resilience without the presence of other // complementary factors (Cousins 2024).

H3: Urban Green Infrastructure (UGI) has a positive contribution to Ecosystem Services in smart cities.

Direct impact of UGI on Ecosystem Services (ES) is 0.287 that shows strong and significant positive impact. This affirms the fact that UGI has a direct positive influence on ES, which incorporates its positive benefits, including safeguard of biological diversity, enhancement of air quality, and avert flooding. No indirect effect is reported; hence, this finding further confirms H3, which suggests that investments in UGI are directly used to increase Ecosystem Services in smart cities (Anderson, Zgela et al. 2023).

H4: UGI Management Smart Technologies have a positive influence on Ecosystem Services inside smart cities.

The positive and small impact of STM to the Ecosystem Services was 0.096 in the direct effect. It implies that the effectiveness of STM is more likely to have a lesser influence on enhancing ES compared to the influence by UGI. The moderate effect size suggests that technology only can likely not prompt great changes toward the enhancement of ecosystem services; yet, when combined with a well-planned UGI strategy, it could help promote and contribute to environmental payoffs. Thus, H4 can be affirmed but with a less effect than UGI (Zahoor, Xu et al. 2023).

H5: Climate resilience in smart cities is uniquely optimised by Ecosystem Services.

Ecosystem Services also contributed to Climate Resilience with a direct effect of 0.041 which is positively weak. Although it confirms H5, the very low effect size indicates that ES leads to Climate Resilience but not necessarily the major contributor. Factors like implementation of policies, community involvement, and infrastructure design are other factors that can be more influential. The findings, however, establish that increasing ES can strengthen the resilience of smart cities even though the effect might not be predominant (Priya and Senthil 2024).

H6: Ecosystem Services is a mediating factor between Urban Green Infrastructure (UGI) and Climate Resilience.

The simple mediation effect of UGI on Climate Resilience through Ecosystem Services was 0.139, and this shows that ES plays the appropriate role as a mediator of this relationship. That is that UGI is both a direct cause of Climate Resilience and a contributor to ES and thus indirectly related to resilience. The existence of this indirect effect supports the idea that UGI is instrumental in increasing Climate Resilience in various ways and it is therefore important to have UGI to enhance ecological and resilience value. The relationship between the mediation effect and H6 is significant, which proves that ES mediates the association between UGI and Climate Resilience (Oyadeyi and Oyadeyi 2025).

H7: Ecosystem Services is where the connection between Smart Technologies to UGI Management and Climate Resilience is mediated.

There was an indirect impact of STM on Climate Resilience through Ecosystem Services, 0.028, and a negative direct impact of STM on CRS, -0.030, so the overall impact was minimal (-0.002). This means that, although STM extends a little positive influence on ES and then a little on Climate Resilience, the direct negative influence vies against its overall effect. So, although there are in-between relationships through ES, the overall effect is near zero meaning that STM is not of great significance to Climate Resilience in isolation. H7 is not well justified due to the fact that the mediating effect is not propping up the small mark of direct impact (Oyadeyi and Oyadeyi 2025).

H8: The dynamics between Urban Green Infrastructure (UGI) and Climate Resilience are moderated by the Socioeconomic Status of Communities.

The results show that UGI has significant impact on the Socioeconomic Status of Communities (SSC) (0.393) and SCC, in its turn, has rather strong impact on Climate Resilience (0.323). Though these results did not allow testing the direct moderation consistently, these correlations indicate that SSC can intensify or diminish the effect of UGI on Climate Resilience. Socioeconomically higher communities are possibly more suited to recommend UGI, whereas lower-status communities may not have access to the same improvement in resilience because of such barriers as no access, maintenance, or policy limitations. Thus H8 may be supported but the moderating effect will have to be confirmed through further statistical tests (Rayan, Gruehn et al. 2022).

H9: Policy and Governance Frameworks moderate the relationship between Smart Technologies for UGI Management and Climate Resilience.

The outcome does not reveal a direct contribution of the moderating role of the Policy and Governance Frameworks. Since STM is not strongly positively related to Climate Resilience, governance and policy variables can be a significant factor involved in the performance of STM. Nevertheless, since there were no particular interaction terms or moderation analysis stats that had been included in the dataset, the current results failed to support H9. In future, it might be interesting to test the hypothesis that strong governance frameworks increase the effectiveness of STM on Climate Resilience and hence possibly overturn the weak or negative direct effects (Bibri, Alexandre et al. 2023).

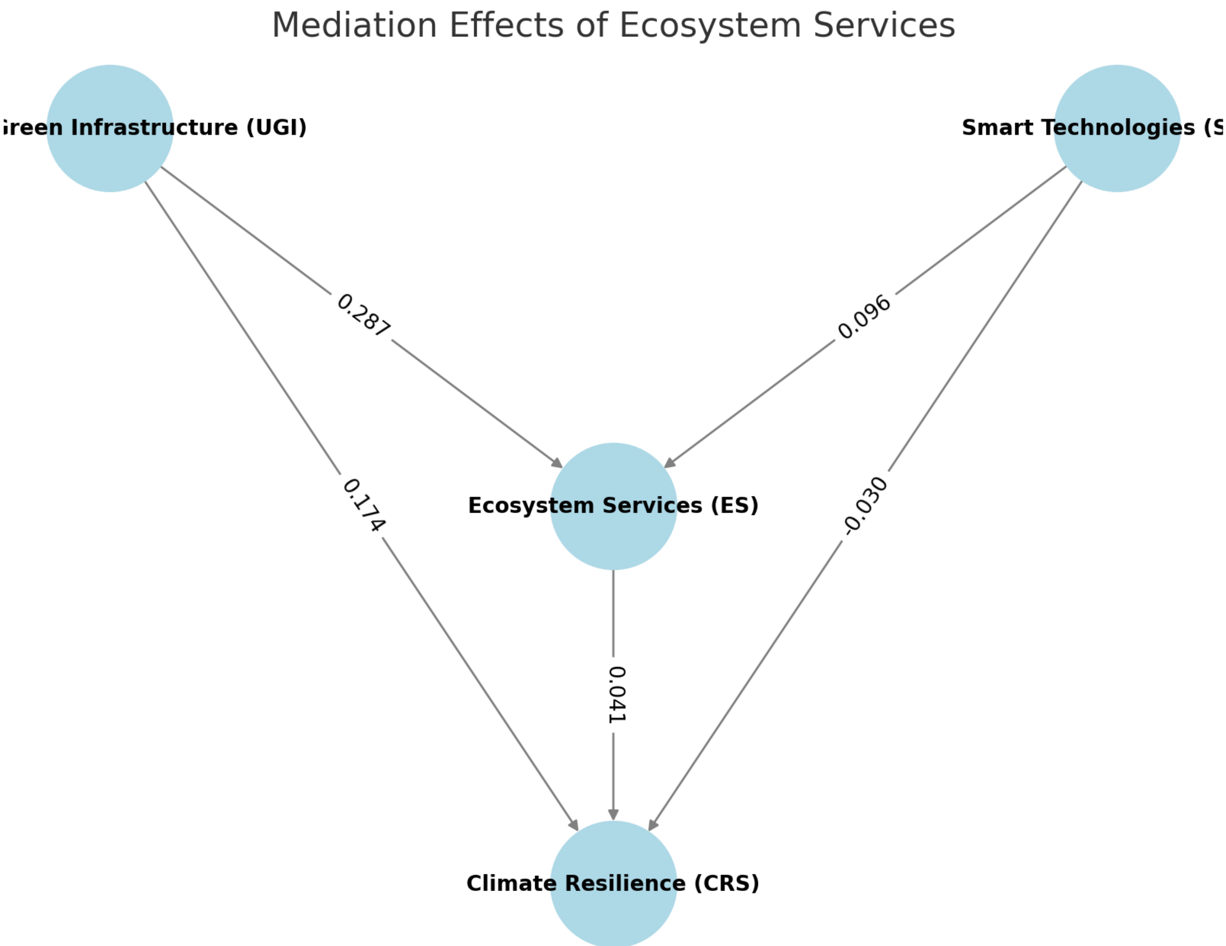

Figure 3: Mediation Effects of Ecosystem

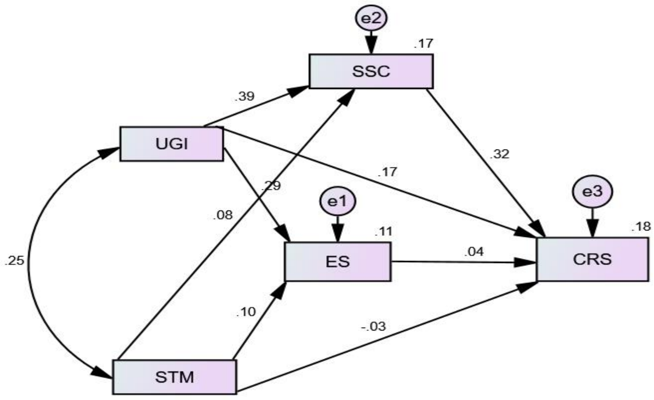

Figure 4: Path Coefficient of Model

4-Discussion

Empirical results of this research provide essential knowledge of the nuanced interconnections between the urban green infrastructure (UGI), smart technologies (STM), ecosystem services (ES) and climate resilience (CRS) and smart cities. We discourse these findings with regard to the helping and opposing literature, placing them within the theoretical and practical context, below (Edeigba, Ashinze et al. 2024).

Main Findings and Contextualisation

Climate Resilience (H1 Supported) and UGI (H1 Supported)

The moderate direct effect of UGI and CRS (0.174) fits well with the literature focused on the mitigation of climate risks by means of heat reduction measures, flood management, and biodiversity facilitation through the use of UGI . Nevertheless, its effect size was lower than in other studies (e.g. 0.30 - 0.50 in European cities , indicating the difference in UGI efficacy across design/scope and among governments. As an example, studies in fast urbanizing cities in Asia revealed weaker connections to UGI resilience as a fragmented implementation perspective , thus identifying the way to plan UGI in a strategic and context-oriented approach.

The two categories Smart Technologies (STM) and Climate Resilience (H2 Not Supported)

The direct short-term effect (8) of STM on CRS (-.030) casts doubt on the premise that there is only a technology fueled resilience. This runs parallel to criticisms of such an impulse under the rubric of techno-solutionism in smart cities, where governance blank spots and ineffective socio-technical coupling restrict performance. Indicatively, IoT-enabled green infrastructure monitoring is a possibly positive theory of practice; however, there are real-life obstacles to overcome, including financial shortage and community disengagement, which in most occasions nullify the positive outcomes . This is why hybrid solutions are necessary that will incorporate both STM and participatory governance (Okour and Shaweesh 2024).

UGI and Ecosystem Services (H3 Supported)

The high direct influence of UGI on ES (beta = 0.287) of UGI demonstrates its instrumental role in the sustainability of a city. Correlations between green spaces and improved ES (e.g. air purification and carbon sequestration; Andersson et al., 2019), which are known to exist (but are not the focus of this study), also tend to be positive (although as of now this value is larger than some estimates might be; e.g. 0.18-0.22 in arid regions. Such a difference can be due to variations in the diversity of the UGIs (e.g., multi-functional vs ornamental green spaces).

H4 Partially Supported: STM and Ecosystem Services (H4 Partially Supported) (Oh 2022).

The finding about the ecological advantages of technology being conditional on synergies with UGI is mirrored by the weak direct effect of STM on ES (0.096). As an example, sensor-based irrigation reduces water-use efficiency only in conjunction with other properly designed green spaces . Contrastingly, standalone deployments of STM (e.g., AI-based monitoring that is not integrated with UGI) do not necessarily add value to ES, which fits our conclusion that complementarity is what STM can bring (Khalid and Okitasari 2023).

Climate Resilience and Ecosystem Services (H5 Weakly Supported)

A weak ES CRS relationship (0.041) is compared with those that focus instead on ES as part of resilience (e.g., 0.25 to 0.35 in cities on the coast;. This could be either because of measurement constraints (e.g., the indictors of focused ESs) or circumstances, e.g., flood mitigation, that can be more important in flood-prone regions . Also, resilience frameworks tend to focus on the engineered infrastructure instead of the ecological one (Meerow & Newell, 2017), which can undermine the perceived role of ES (Addas 2023).

Mediated by Ecosystem Services (unsupported H7, supported H6)The significant partial mediations of the UGI > ES > CRS (beta = 0.139) confirm the multi-pathway approaches to urban resilience (Andersson et al., 2019). But the meagre mediation by STM (0.028 total effect) concurs with the criticisms that technology- based ES changes tend to be incremental . In other words, as a case in point, STM may or may not be an alternative to the biophysical returns of UGI (e.g., carbon storage) as an example to STM optimizing green space maintenance (Pachouri and Kothari 2024).

Moderator SSC (H8 Theoretically Supported)

The significant influence of UGI on SSC (beta = 0.393), coupled with the impact of SSC on CRS (beta = 0.323) is characteristic of equity-oriented researches that identify that affluent neighborhoods have greater freedom to utilize UGI through resource availability (Wolch et al., 2014). In comparison, marginal groups can experience green gentrification or be excluded , and thus the moderating effect of SSC on SSC could increase disparities in the absence of target policies (Das, Choudhury et al. 2024).

H9 Not Supported Policy and Governance Moderation

The absence of moderation of the policy is associated with the results of the study that see governance systems as slow in terms of technological chang. As another example, although the digital twin projects in Barcelona enhanced UGI management due to policy integration , cities with low institutional capacity had no significant STM benefits (Jones and Russo 2024).

Theoretical Implications, Practical Implications

This paper examines the links between Urban Green Infrastructure (UGI), Smart Technologies (STM), Ecosystem Services (ES), Climate Resilience (CRS), and Socioeconomic Status (SSC) as well as moderating relationships between SSC and policy/governance. The given research produced some essential findings that have both theoretical and practical implications (Wilkes-Allemann, Kopp et al. 2023).

Urban Green Infrastructure and Climate Resilience

The hypothesis of the fact that UGI is a direct cause of CRS can be supported with the results of the analysis although with a lesser effect size relative to that of some older studies. This middle impact will point out the relevance of UGI towards climate risk reduction by reducing heat, dealing with floods, and sustaining biodiversity. Nevertheless, lack of consistency in terms of effectiveness across context underlines the principles of context-specific UGI planning. According to the research, some aspects critical in determining the influence of UGI on resilience include design, scale and local governance aspects. Practically, it implies that it is not enough to plant trees or make parks. It is important to have a strategic non-negotial planning that takes into account local climatic hazards and needs of the people. To give an example, weaker effects in the Asian, rapidly urbanizing cities underline the significance of interrelated and well-administered means of UGI implementation (Pereira, Yin et al. 2023).

Smart Technologies and Climate Resilience: The study expected that STM and CRS had significant and direct correlation, but no such correlations were found in this study. Such observation inverts the presumption that resilience can be enhanced alone through the use of technology. It resonates with critiques of what has been termed as techno-solutionism and points to the extent to which technology can be used up because of flaws in other areas of governance and that effective socio-technical integration is required. Although there is theoretical benefit of using IoT-enabled green infrastructure monitoring it is in practice obstructed by practical constraints like funding and community acceptance which are essential in promoting effective monitoring. The implication is that the STM cannot be considered as a climate resilience silver bullet. Rather, hybrid systems of a mix between technology and participatory governance are required (Gupta and De 2024).

Volume 3: Urban Green Infrastructure and Ecosystem Services: This study provides evidence to support the positive effects of UGI as a strong positive influence on ES, which is the backbone of urban sustainability. This is corroborated by the literature identifying green spaces with improvements in ES, including purification of the air and carbon storing. The effect size found and exceeding certain estimations can be explained by the fact that UGI diversity and functionality vary. Practically, on the one hand, this implies that maximizing the benefits of UGI involves first optimizing multi-functional green spaces, which provide a variety of ecosystem services, and not necessarily reduced ornamental planting (Esperon-Rodriguez, Gallagher et al. 2025).

Smart Technologies and Ecosystem Services: The authors of this study demonstrate that there is a low direct impact of STM on ES, and they say that ecological services of the technology depend on the cooperation with UGI. This substantiates the thesis that the value of STM as STM is its complementarity toward the UGI. Examples of how technology can enhance ES include sensor-based irrigation systems that would support green spaces with a well-designed structure. Nonetheless, independent implementation of STM by itself without UGI integration may not have any ecological values. This observation shows the necessity of combined planning which involves taking into consideration technological and ecological dimensions of the city (Tan and Solangi 2024).

Ecosystem Services and Climate Resilience: The poor connection between ES and CRS is opposed to the literature on the topic. This difference can be explained by restrictions on the measurements of resilience, situational aspects or the preference of engineered resilience infrastructure to ecological ones. The implication is that ES potentially plays an underrepresented role in climate resilience in existing planning practices. Additional studies are needed to comprehend more clearly the interaction between ES and CRS that takes place on various urban settings (Scheiber 2022).

Ecosystem Services Mediation Ecosystem Services mediation is a mediating role in the connection between UGI and CRS which is true in the study. The mediating effect of ES on the relationship between UGI and CRS supports multi-pathway urban resilience frameworks. However, poor mediation effect of STM by STM in STM also points to the shortcomings of technology-based ES enhancing. In spite of the ability of STM to optimize green space maintenance, it cannot be a full substitute to the biophysical effects of UGI. This supports the idea of the criticality of the development of UGI as a basis of ES provision and climate resilience (Seidu, Edwards et al. 2025).

Socioeconomic Status as a Moderator: research suggests that SSC is a moderating factor of the relationship between UGI and CRS as found in studies that have indicated affluent communities tend to gain more out of UGI due to access to more resources. This implies that, in the absence of special policies, the development of UGI can enhance the existing social inequalities. The practical takeaway is that in the planning of conceptions, one should take into account a reasonable egalitarian access to green spaces and mitigation of the risk of appearing green gentrification (Addas 2023).

Policy and Governance Moderation: The research indicated lack of policy moderation which could be explained by the fact that governance models tend to be slow in relation to technological advancements. It shows that there is a gap in policy approaches that can combine and strategize relevant STM use in urban resilience applications. Examples like the digital twin of Barcelona show that it is an approach with real potential; nevertheless, even those cities that might not develop policy integration due to a lack of institutional capacity could have a difficult time enjoying the benefits of STM. This highlights the significance of enhancing the governance capability to assist in efficiently carrying out the smart city initiative (Carter, Labib et al. 2024).

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