Enhanced Communication Systems with Reconfigurable Intelligent Surfaces in Smart Cities: Bridging Wireless Connectivity and Urban Sustainability

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1 ABSTRACT

The growing need for communication systems in urban areas working at high-speed and energy-efficient has led to developing smart city infrastructures. This article exploits the incorporation of Reconfigurable Intelligent Surfaces (RIS), as a sustainable approach, into urban environments to enhance the connectivity and the energy efficiency of the wireless communication, while exploring their architectural and engineering integration into the fabric of smart cities. Unlike previous approaches, which have traditionally focused on electromagnetic optimizations, this paper proposes RIS as an innovative architectural component that has the potential for integrating wireless communication and sustainability into smart cities. The approach utilizes a multi-step methodology, beginning with an analysis of architectural, structural, and communication needs for designing criteria for implementation. Additionally, this paper proposes a co-design approach for designing geometry and RIS implementation at the same time, which will focus on functional efficiency and aesthetic consistency. Optimization of RIS placement and orientation will be optimized using simulation analysis, taking into consideration signal propagation, energy efficiency, in addition to urban context constraints. The specific RIS modules will be integrated into façade panels and architectural elements using material, structural, and visual strategies. Finally, implementation of this integrated solution will then be assessed for performance on communication, energy efficiency, and aesthetic implementation. By the intelligent reflection of the electromagnetic waves, RIS can transform conventional architectural structures into active communication elements to bridge the gap between wireless connectivity and sustainable urban development. The results aid in the development of future intelligent, energy-efficient, and aesthetically pleasing of future cities.

Keywords: Urban Sustainability, Reconfigurable Intelligent Surfaces , Enhanced Communication Systems , Smart Cities, Urban Planning

2 INTRODUCTION

The rapid growth of cities with urban populations and the increasing demand for high-capacity wireless communication systems have made cities to be smart and data-driven environments (Ouafiq, et al., 2022; Sharma, et al., 2024). To provide real-time services, smart cities need seamless wireless connectivity. This includes smart transportation, environmental monitoring, and sustainable energy management. However, the congested architectural landscape and urban environment can lead to significant signal obstructions, multipath fading, and inadequate energy utilization, which makes modern wireless networks less reliable and less efficient (Akyildiz, et al., 2020)(He, et al., 2024).

In the last years, Reconfigurable Intelligent Surfaces (RIS) have become a promising technology for improving communication performance. RIS can turn passive structures like building façades and walls into active surfaces that improve wireless communication by changing the phase of the reflected electromagnetic waves intelligently. This ability makes RIS an appropriate choice to be used in smart cities, where buildings redesigned to include RIS (Alhafid, et al., 2024; Kisseleff, et al., 2020). In addition to RIS functionalities of improving wireless performance and resources optimizing, it is passive and operates at low-energy, so it has a lot of potential for making cities more sustainable and can satisfy the principle of green infrastructure (Amin, et al., 2023; Salim et al., 2025).

From the perspective of architectural engineering and sustainable urban design, it is important to emphasize the role of communications technologies in the built environment. Accordingly, this paper investigates the alignment of wireless communication engineering and urban sustainability through the architectural integration of RIS. It proposes a framework of integrating RIS into smart city to improve data transmission and facilitate sustainable urban cites, also emphasizes the collaborative aspects of this approach by encouraging communication engineers, architects, and urban planners from different fields to work together to create the promised future sustainable cities.

3 LITERATURE REVIEW

The use of advanced communication technologies in urban infrastructures has emerged as a fundamental aspect of smart city evolution. Researchers over the past decade have investigated and studied many techniques to improve wireless performance in densely populated cities. Some of these studies include massive MIMO technology, high-frequency communication technology (such as millimeter-waves), and network densification. But these solutions often exhibit energy consumption, and require complex deployment, which makes them less useful for sustainable city models.

To mitigate these challenges, RIS has been proposed as a revolutionary paradigm for next-generation wireless communications. Early works, such as (Kisseleff, et al., 2020) and (Bjornson, et al., 2022), proved that RIS can be leveraged to improve signal-strength and coverage in non-line-of-sight (NLoS) urban areas by intelligently adapting the EM reflections. Other works, such as (Basar, et al., 2021) and (Du, et al., 2021), proved that RIS-assisted communications can provide a considerable enhancement in spectral and energy efficiency over other conventional methods such as relaying and beamforming. Recent works have explored the application of RIS for smart city and urban communications. For instance, the work presented in proposed the wireless environment as a service paradigm through RIS that can be embedded in buildings to optimize the wireless environment. Also, the work presented in (Sang, et al., 2024) explored the application of RIS-equipped buildings for filling coverage gaps in urban areas. On the other hand, works (Alhafid, et al., 2024) and (Alhafid, et al.,2023) explored the application of RIS-assisted localization for near-field localization and proposed new methods using multi-RIS configurations and efficient beam sweeping strategies, respectively. Even with these improvements, most of the research is still focused on communications technologies rather than integrating RISs into architecture or urban planning.

From the sustainability and intelligent design principles point of view, the subject of the built environment has become an important issue in modern architectural engineering studies (Ahmed, et al., 2025; Ahmed, et al.,2024). The authors in reference (Kadhim, et al., 2025) prove that adaptive façade systems improve the energy efficiency of buildings based on weather changes and therefore improve the comfort and energy efficiency of buildings. The authors further argue that smart materials and new ideas in quantum energy can improve the adaptability and efficiency of façades and therefore support adaptive façades as a sustainable solution in architectural engineering. The authors in reference (Corti, et al.,2023) investigate photovoltaic shading systems and argue that such systems can be an effective solution in preventing overheating and allowing for renewable energy implementation. The authors further argue that studies on this subject are still limited. In (Fathi, et al., 2025), the authors conduct a comprehensive analysis and indicate that active and passive smart materials for façades can be an effective solution in improving energy efficiency and preventing overheating in buildings. The authors (Almeida, et al.,2023) investigate a dynamic thermal insulation system and argue that such a system can easily and quickly alternate between different insulation values and therefore can be an effective solution in preventing overheating and ensuring comfortable temperature inside buildings.

Despite the increasing research on RIS, most current research on this subject is largely focused on electromagnetic optimization and network-level performance, overlooking the architectural integration and spatial design potential of RIS in the urban context built environment. At the same time, research on architectural design concepts on building façades is largely concentrated on sustainable design, efficiency, and current design trends, often without taking into consideration wireless connectivity needs. This state of affairs points to a significant research gap, since there is currently no comprehensive framework integrating wireless communication performance, architectural design, and sustainable urban development, a necessary synthesis for developing intelligent, efficient, and interconnected smart cities in the future. Building façades, and public structures have a vast number of surfaces that are geometrically varied and extensive, making them an excellent fit for the application of RIS to increase coverage, facilitate sensing capabilities, and lower transmission power. However, studies on RIS applications have rarely investigated their application through the lens of architectural design concepts, material characteristics, and urban aesthetics. To the best of our knowledge, this issue has not yet been directly treated by current research on this subject. Based on this research gap, this paper proposes to consider RIS applications through an architectural design lens, thus diverging from an exclusively electronic design approach to integrating applications of RIS into urban planning and sustainable development goals, thus promoting a multidisciplinary approach to next-generation smart city design.

4 THE PROPOSED METHODOLOGY

The proposed multi-stage methodological framework in this research combines RIS into building façades in a smart sustainable urban environment. To begin, there is an initial stage where architectural, structural, and wireless communication requirements are considered collectively in setting common design principles. Next, there is a stage where a co-design strategy is employed, where geometric design of façades and RIS are done simultaneously. Third, there is an RIS placement stage where simulations are done based on position, orientation, signal propagation, and urban environment constraints. Fourth, there is a stage where RIS modules are integrated into façades using material, structural, and visual models. Finally, there is an RIS-integrated façade system assessment stage where communication, energy, and architectural design are considered. This multi-stage methodological framework makes it possible to fully integrate RIS technology into sustainable architectural design principles. The overall process of this multi-stage methodological framework is shown in Figure 1.

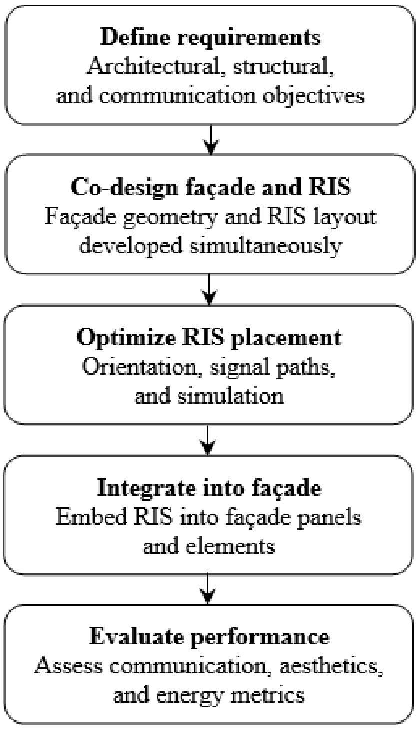

Figure 1 The proposed multi-stage methodology framework

4.1 Development of Urban Geometry Models

In order to properly assess the mutual impact of RIS and the surrounding environment, models of urban geometry can be developed to describe the physical and spatial features of the realistic urban areas for accurate wireless propagation and integration. A typical urban environment (like residential areas, streets, etc.) is first described, with buildings, roads, open spaces, and other environmental features included which can influence the signal behavior. The buildings' geometry is then developed with parameters of footprint, height, and interval between buildings. The façades of the buildings can be specifically described with consideration of their orientation angle, and architectural details like recesses, balconies, and shading. The developed façades are then divided into candidate regions for RIS placement. The regions are described with parameters of orientation angle, height from ground level, surface area, and accessibility. The properties of each surface material for each façade region are described with consideration for surface reflectivity, roughness, and other electromagnetic properties. The regions for deployment of RIS are determined based on their integration with buildings' architecture and relevance to regions with deficient coverage and blocked areas of urban regions. The process of deployment of urban model for placement of RIS is described with illustrations of each step as depicted in Figure 2.

Figure 2 RIS placement development in urban model

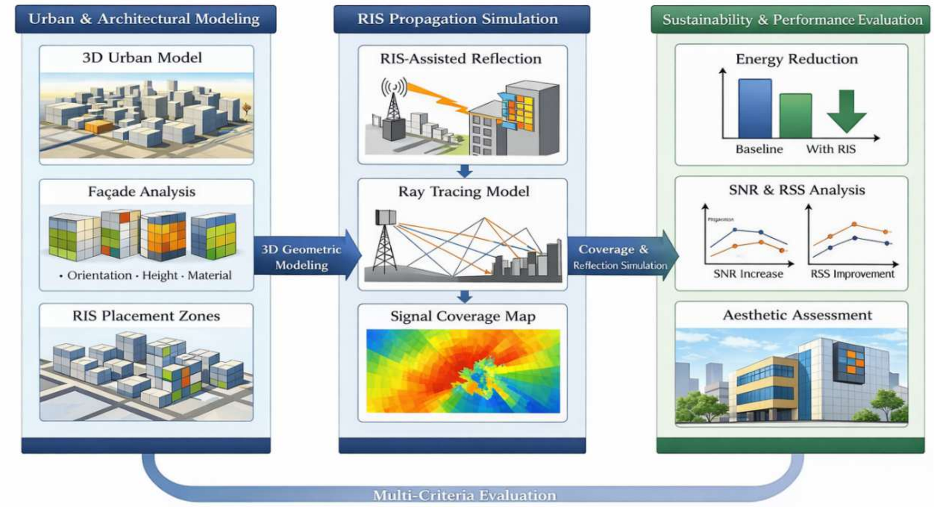

Figure 3 RIS integration in urban environments

4.2 Evaluation of RIS Coverage and Reflection Performancer

Subsequent to the creation of the urban model, the performance of RIS-assisted wireless communication is simulated and evaluated by incorporating the geometric model of the urban environment and communication performance to determine the effect of architectural design on the efficiency of RIS- assisted communication performance. The performance of the communication channel without RIS, which is the baseline propagation scenario, would be simulated first to determine the areas of poor coverage and the non-line of sight (NLoS) areas created by urban structures. The RIS panels would then be virtually placed on the selected areas of the façades, and the panel dimensions, position, and orientation can be varied to determine the effect of the panels on signal redirection behavior. Each RIS would simulate phase and amplitude modulation of the reflected electromagnetic waves to provide beam steering toward desired areas, especially areas with poor coverage in the NLoS region. The performance of the communication system would be measured based on indicators such as the received signal strength (RSS), signal-to-noise ratio (SNR), coverage, and improvement if energy efficiency compared to the baseline scenario. Several scenarios would then be compared to determine the best approaches for RIS panels placing. Figure 3 illustrates the design and evaluation procedure for incorporating RIS into urban architecture through a multidisciplinary design and evaluation approach.

5 ARCHITECTURAL AND ENVIRONMENTAL INTEGRATION OF RIS-ENABLED FAÇADES

In order for RISs to be incorporated into the façade of buildings, it is essential that these be designed to optimize not only the performance of wireless communication but also take into account architectural and environmental aspects, such as those related to solar exposure and thermal performance of the façade of buildings. Because RISs installed on the façade of buildings are inherently exposed to solar radiation, the angle of installation, size of the RIS panel, height of installation, and material properties will simultaneously impact the efficiency of electromagnetic reflection and may the demand of buildings cooling. Hence, the deployment of RISs can be treated as a multi-objective optimization problem that aims to maximize a combination of communication performance (such as SNR, coverage, and beam steering) and architectural requirements, as listed in Table 1.

From an architectural perspective, RIS panels may be seen as multi-functional façade systems that function similarly to external solar shading systems, perforated metal screens, or double skin façade layers. As such, RIS components may be utilized to mitigate solar gain in highly exposed façades, control glare, and function as a thermal buffer while also re-radiating wireless signals into dense urban environments, as shown in Table 2. At a larger urban scale, dual-functionality provides a means by which buildings may interact with and influence both climates and electromagnetic environments, thus lowering cooling demands, improving pedestrian thermal comfort, and increasing the reliability of outdoor wireless communications. The complete process flow for façade system modeling and placement with awareness of RIS components within urban environment is shown in Figure 4.

Aspect	Communication Perspective	Architectural Perspective	Integrated Outcome
Façade orientation	Determines reflection direction and coverage	Controls solar exposure and heat gain	Orientation-aware RIS placement
RIS surface area	Affects beamforming gain	Influences shaded façade area	Balanced panel sizing
Material selection	Improves LoS and NLoS coverage	Alters solar incidence patterns	Optimized vertical positioning
Phase configuration	Impacts reflection efficiency	Affects absorptance and transmittance	Material-aware RIS design
Solar gain constraint	Maximizes SNR at users	No direct solar impact	Independent control variable
Optimization objective	Not considered in classical RIS	Limits overheating risk	Thermal-safe RIS deployment
Material selection	Maximize SNR / coverage	Minimize cooling load	Multi-objective optimization

Table 1 Communication and architectural criteria for RIS placement

RIS Architectural Role	Solar / Thermal Effect	Architectural Benefit	Wireless Communication Function
External shading element	Reduces direct solar heat gain on exposed façades	Improves thermal comfort and wireless coverage	Redirects signals into non-line-of-sight urban areas
Perforated façade screen	Controls glare and limit solar penetration	Enhances façade articulation and aesthetics	Enables controlled signal reflection and scattering
Double-skin façade layer	Provides shading and thermal buffering	Enables discreet RIS integration	Creates optimized signal reflection paths
Adaptive façade component	Responds dynamically to solar conditions	Facilitates smart building operation	Supports reconfigurable beam steering
Urban infrastructure surface	Reduces cooling demand at district scale	Contributes to smart city resilience	Improves street-level connectivity

Table 2 Architectural and communication functions of RIS-integrated façades

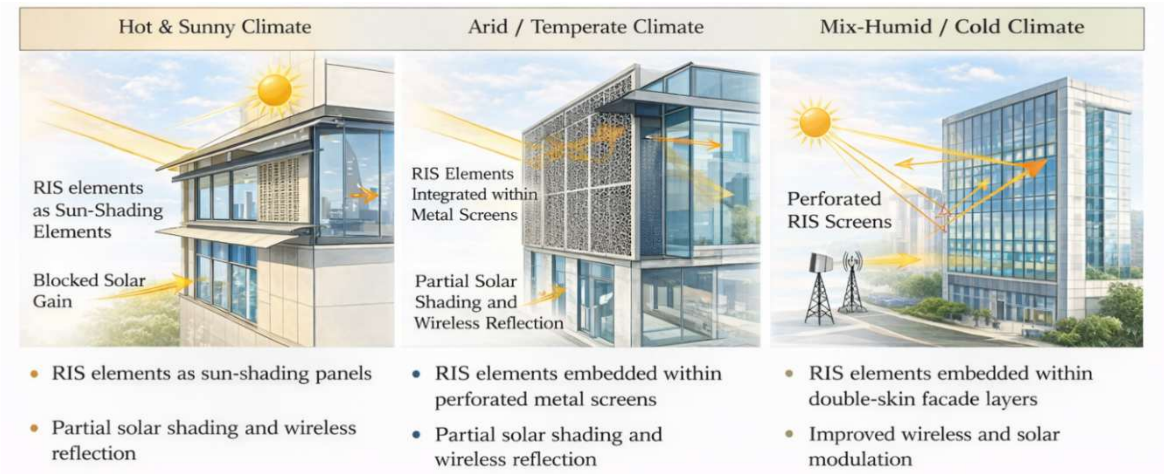

Figure 4 RIS as façade solutions

6 SYSTEM MODEL AND SIMULATION SETUP

The considered system model describes a two-dimensional urban communication scenario, as depicted in Figure 5, where a single BS transmits signals to multiple user equipment (UE) distributed in an area with several building blocks that cause LoS and NLoS propagation scenarios. A set of candidate RIS positions are pre-defined on building walls and urban infrastructure components, considering practical architectural constraints of RIS deployment. Based on this set, two RISs (K=2) are chosen to meet the optimum performance objectives. Three communication scenarios are investigated: (i) a baseline system without RIS, (ii) an RIS-based system with non-optimized RIS positions, where RIS are randomly chosen from the predefined set, and (iii) an RIS-based system with optimized RIS positions, where both RIS positions are exhaustively searched to achieve maximum performance gains. Each RIS is made of certain number of passive elements and employs different phase shift configurations, such as random, quantized, and ideal beams teering schemes. For RIS-based communication systems, received signal powers are calculated considering joint BS-RIS and RIS-UE channels with reflection efficiency, and effects of partial blockages.

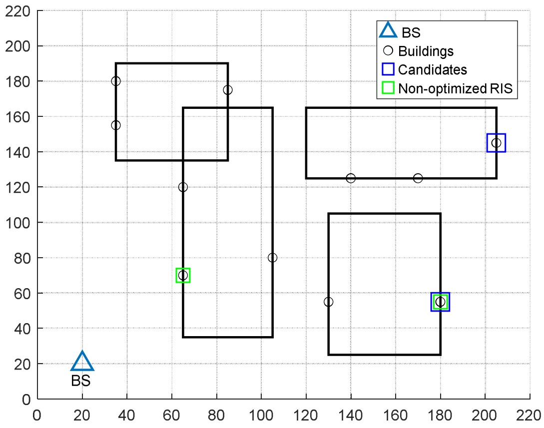

Figure 5 The Considered System Model

The number of RIS elements is assumed to be N elements and $n = 1,2, \ldots N$ is the sequence of each element. System performance metrics are measured by average SNR and spatial SNR heatmaps, as well as by improvements in SNR and in energy efficiency, allowing an overall performance comparison of baseline, non-optimized, and optimized RIS deployment schemes. The received signal observed by the UE can be represented as in (Alhafid, et al., 2023; Alhafid, A.K., Mohammed Ali, et al.,2023):

$$y = h^d x + \sum_{n=1}^{N} \Upsilon_n \left(h^f h^b\right) x + n \qquad (1)$$

where h^d is the direct channel between the BS and the UE, x is the known transmitted signal, $h^f$is the channel from the BS to the RIS. $h^b$is the channel from the RIS to the UE, $\Upsilon_n$is the reflection coefficient of the n^{th} element where $n \in \{1,2,\dots N\}$ and $n$is an additive Gaussian Noise.

The reflection coefficient of the n^{th} element possesses an amplitude of Υ and a phase of ψ, which is configured according to the designed profile, so,

$$\Upsilon_n = \Upsilon e^{j\psi} \tag{2}$$

Noting that the channel from the BS to the UE through the RIS is cascaded channel consist of forward $h^f$and backward coefficient h^b.

7 RESULTS AND DISCUSSION

The results shown in Figures 6–9 illustrate the key importance of RIS placement optimization, number of RIS elements, (i.e. RIS size), and phase shift configuration on system performance for dense urban scenarios. As shown in Figure 6, the optimized RIS placement always yields better performance compared to the non-optimized (candidate) placement for all RIS sizes. This highlights that only increasing RIS size is insufficient without appropriate spatial RIS placement, and improper placement is responsible for restricting the possible gain and the beamforming of the reflected signal. Figure 7 further reinforces this observation by showing that optimized RIS placement is responsible for providing significant SNR within the regions of low coverage and NLoS, while the corresponding regions for the baseline case are dominated by the low SNR values due to the blockages created by the buildings.

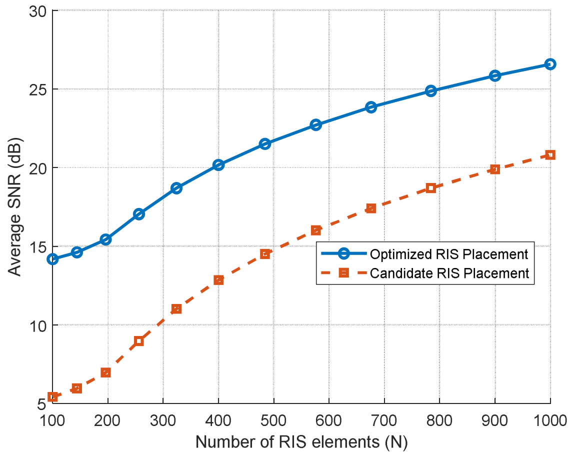

Figure 6 Average SNR versus number of RIS elements for optimized and candidate RIS placement

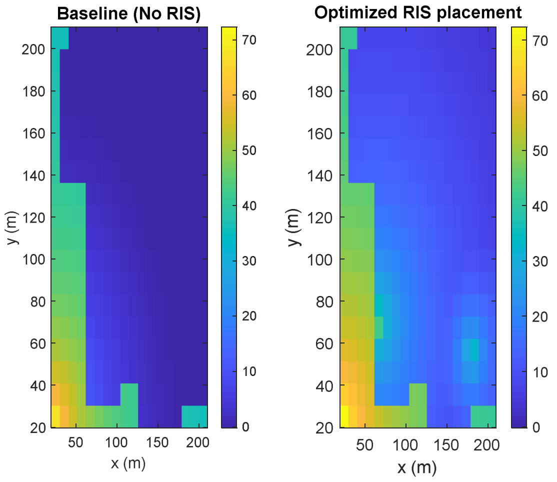

Figure 7 SNR heatmaps for baseline and optimized RIS-assisted communication

The impact of RIS phase profile is then investigated in Figure 8, where ideal beam-steering RIS phase profile provides best SNR gains. Followed by the quantized phase profile which offers a good trade-off between performance and hardware complexity. On the other hand, random phase profile provides little or negligible performance benefit, emphasizing the need for phase optimization. Finally, it is shown in Figure 9 that properly designed and optimized RIS systems can provide considerable power savings (may reach 60%) for larger RIS sizes. According to these results, communication systems utilizing RISs can significantly enhance SNR, improve coverage, and make energy efficiency better conditioned by the size, placement, and phase profile configuration of the RIS are optimally calibrated.

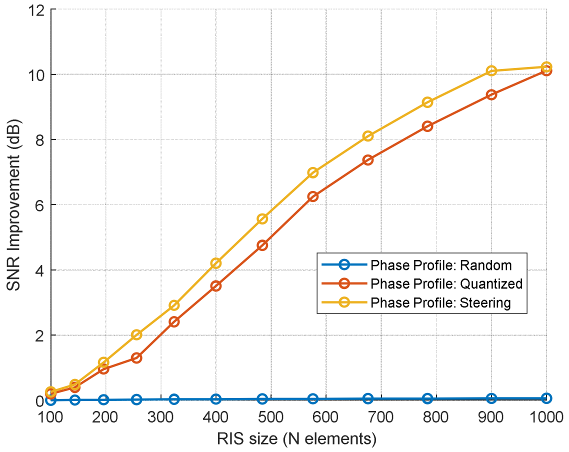

Figure 8 SNR improvement versus RIS size under different RIS phase profiles.

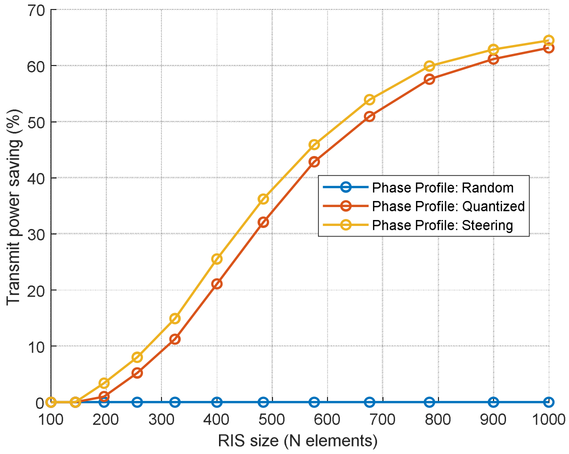

Figure 9 Power saving versus RIS size for different RIS phase profiles

8 CONCLUSION

This paper explored the inclusion of RIS in urban areas from a unified wireless communication and architectural engineering point of view. Unlike most RIS-related research that focuses exclusively on communication optimization techniques, this study considered RIS to have a multifunctional role in façades that could contribute to simultaneous improvements in wireless communication performance and environmentally responsive architecture. A comprehensive framework has been proposed for integrating architectural modeling, geometric of urban areas, and communication optimization. Various RIS placement strategies have been analyzed by simulation. These strategies include communication without RIS, non-optimized RIS placement, and optimized RIS placement by exhaustive search. The results have shown that optimized RIS placement strategies outperform non-optimized strategies significantly, especially for NLoS areas of urban regions. In addition, increasing the number of RIS elements with beam-steering or quantized RIS phase profile has led to considerable improvements in SNR, coverage, and energy efficiencies. The results have shown that RIS are effective in overcoming urban blockage issues while providing considerable energy savings. RIS are thus highly appropriate for sustainable wireless communication. From the architectural engineering point of view, RIS have been found to be integratable with existing architectural façades such as shading devices, perforated screens, or double-skin façades. In conclusion, RIS are identified here as a vital enabling technology for future smart cities where buildings are active participants in wireless communications and environmental regulation. Future works can extend this framework to more practical urban scenarios, and real-world architectural constraints, as well as explore experimental validation within smart and sustainable city ecosystems.

9 REFERENCES

Ahmed, J.A., Fatimah, W., Yusoff, M., Mohamed, M.F. : Instrumentation Mesure Métrologie Validation Field-Measured Data Through Design-Builder Simulation Software of Indoor Air Temperature in A Modern Residential Building in Erbil , Iraq. In: , pp. 131–141, 2025.

Ahmed, J.A., Fatimah, W., Yusoff, M., Mohamed, M.F. : The Impact of Traditional Architectonic Characters on the Environmental and Thermal Condition of Houses : A Case Study of Erbil , Kurdistan , Iraq. In: , pp. 1969–1982, 2024.

Akyildiz, I.F., Kak, A., Nie, S. : 6G and Beyond: The Future of Wireless Communications Systems. In: IEEE Access, pp. 133995–134030, 2020.

Alhafid, A.K., Mohammed Ali, Y.E., Younis, S. : Performance Investigation of RIS Aided Localization with TDoA in the Near-Field. In: Mathematical Modelling of Engineering Problems, pp. 2127–2134, 2023.

Alhafid, A.K., Mohammed Ali, Y.E., Younis, S. : Performance Investigation of RIS Aided Localization with TDoA in the Near-Field. In: Mathematical Modelling of Engineering Problems, pp. 2127–2134, 2023.

Alhafid, A.K., Younis, S., Ali, Y.E.M. : Enhanced Far-Field Localization Scheme Using Multi-RIS and Efficient Beam Sweeping. In: Progress In Electromagnetics Research C, pp. 163–175, 2024.

Alhafid, A.K., Younis, S., Mohammed Ali, Y.E. : Efficient near-field localization aided with reconfigurable intelligent surface using geometric dilution of precision. In: Journal of Information and Telecommunication, pp. 208–230, 2024.

Alhafid, A.K., Younis, S., Mohammed Ali, Y.E. : Efficient near-field localization aided with reconfigurable intelligent surface using geometric dilution of precision. In: Journal of Information and Telecommunication, pp. 1–23, 2023.

Almeida, R.M.S.F., Teles-Ribeiro, M., Barreira, E. : Characterization of a Wall System with Dynamic Thermal Insulation – Experimental Campaign and Numerical Simulation. In: Energies, 2023.

Amin, A. Al, Hong, J., Bui, V.H., Su, W. : Emerging 6G/B6G Wireless Communication for the Power Infrastructure in Smart Cities: Innovations, Challenges, and Future Perspectives. In: Algorithms, 2023.

Basar, E., Yildirim, I. : Reconfigurable Intelligent Surfaces for Future Wireless Networks: A Channel Modeling Perspective. In: IEEE Wireless Communications, pp. 108–114, 2021.

Bjornson, E., Wymeersch, H., Matthiesen, B., Popovski, P., Sanguinetti, L., Carvalho, E. De : Reconfigurable Intelligent Surfaces: A signal processing perspective with wireless applications. In: IEEE Signal Processing Magazine, pp. 135–158, 2022.

Corti, P., Bonomo, P., Frontini, F. : Paper Review of External Integrated Systems as Photovoltaic Shading Devices. In: Energies, 2023.

Du, L., Zhang, W., Ma, J., Tang, Y. : Reconfigurable Intelligent Surfaces for Energy Efficiency in Multicast Transmissions. In: IEEE Transactions on Vehicular Technology, pp. 6266–6271, 2021.

Fathi, S., Fakhraeimanesh, S. : Smart materials in building façades: A systematic review of applications and impacts on energy efficiency. In: Energy Reports, pp. 2123–2140, 2025.

He, W., Chen, M. : Advancing Urban Life: A Systematic Review of Emerging Technologies and Artificial Intelligence in Urban Design and Planning. In: Buildings, 2024.

Kadhim, B.M., Maamory, A.S. Al, Ghaban, A.M. Al : Advancing adaptive facades for a sustainable future in building design. In: Edelweiss Applied Science and Technology, pp. 801–845, 2025.

Kisseleff, S., Martins, W.A., Al-Hraishawi, H., Chatzinotas, S., Ottersten, B. : Reconfigurable Intelligent Surfaces for Smart Cities: Research Challenges and Opportunities. In: IEEE Open Journal of the Communications Society, pp. 1781–1797, 2020.

Ouafiq, E.M., Saadane, R., Chehri, A., Wahbi, M. : 6G Enabled Smart Environments and Sustainable Cities: an Intelligent Big Data Architecture. In: 2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring), pp. 1–5, 2022.

Salim ALRikabi, H.T.H., Sallomi, A.H., KHazaal, H.F., Magdy, A. : Review of the Reconfigurable Intelligent Surfaces in Smart Cities: Opportunities, Challenges, and Applications. In: IET Smart Cities, pp. 1–28, 2025.

Sang, J., Yuan, Y., Tang, W., Li, Y., Li, X., Jin, S., Cheng, Q., Cui, T.J. : Coverage Enhancement by Deploying RIS in 5G Commercial Mobile Networks: Field Trials. In: IEEE Wireless Communications, pp. 172–180, 2024.

Sharma, S., Popli, R., Singh, S., Chhabra, G., Saini, G.S., Singh, M., Sandhu, A., Sharma, A., Kumar, R. : The Role of 6G Technologies in Advancing Smart City Applications: Opportunities and Challenges. In: Sustainability (Switzerland), 2024.