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Green roofs as a catalyst for sustainable urbanization in China: Assessing economic feasibility and environmental impact through a scalable business model

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Abstract

Rapid urban development in China has resulted in a series of environmental issues, such as urban heat islands, increased energy demand, and intense stormwater runoff. Green roofs, which transform unused rooftop space into vegetated areas, are a potential solution to mitigate these problems. This study appraises the potential of green roofs as a sustainable urban intervention in the Chinese context with a focus on both economic and environmental benefits. Through a mixed-methods framework, the study leverages international best-case scenarios, expert interviews, and economic cost-benefit analysis to evaluate the feasibility of green roofs in China's urban centers. The study finds key benefits for the urban landscape, including lower energy demand, stormwater management, carbon sequestration, and improved air quality, along with increased property values and employment opportunities. Although these benefits exist, challenges related to upfront costs, regulatory complexity, and low stakeholder awareness hinder widespread uptake. This study suggests a scalable business approach integrating financial incentives, technological innovation, and public-private partnerships to overcome these challenges and encourage large-scale green roof adoption. It provides practical solutions for policymakers, developers, and other stakeholders who wish to incorporate green infrastructure into China's urban development. Future studies should focus on long-term performance assessments, technological innovations in maintenance, and strategies to build stakeholder support and raise awareness.

Keywords: Green roofs, sustainable urbanization, business model, energy savings, China, carbon neutrality

Introduction

China's fast urbanization over later decades has changed its cities but moreover presented squeezing natural challenges. Urban ranges presently confront heightens urban warm island (UHI) impacts, with temperatures rising by up to 4°C compared to encompassing provincial zones, driving to expanded vitality request for cooling. In expansion, stormwater runoff has surged due to the extension of impenetrable surfaces, causing visit urban flooding and overpowering seepage foundation. Together, these issues contribute essentially to China's developing carbon outflows and debase urban living conditions, underscoring the critical require for maintainable urban advancement solutions. Green roofs—vegetated housetop systems—have picked up universal acknowledgment as a multifunctional methodology to combat these urban challenges. Ponders show that green rooftops can decrease building vitality utilization by 20-30%, especially cutting cooling costs in hot climates. In Singapore, for illustration, green rooftops have illustrated up to a 30% diminishment in cooling vitality utilize, whereas in Copenhagen, they have made a difference diminish stormwater runoff by about 50%, facilitating surge dangers. In addition, green rooftops contribute to urban discuss quality advancement by sifting toxins and sequestering carbon dioxide, with potential yearly carbon capture rates of 25-30 kg CO₂ per square meter. Past natural benefits, green rooftops can too amplify the life expectancy of material materials and increment property values by 5-15%, making them alluring investments. Despite the clear preferences, the broad selection of green rooftops in China remains restricted. Current advertise gauges recommend

the green roof industry was esteemed at around ¥1.2 billion in 2023, with anticipated yearly development rates of 30-40% in coming a long time, but these figures still reflect a little share of the add up to urban development segment. Tall forthright establishment costs, extending from ¥500,000 to ¥800,000 for huge commercial ventures, show a noteworthy budgetary obstruction. Furthermore, administrative systems over Chinese cities are divided, and mindfulness among designers and property proprietors around long-term benefits remains moo. These components collectively obstruct the scaling of green rooftops in urban China. Addressing this crevice requires not as it were specialized and natural approval but too strong, versatile commerce models that adjust financial achievability with supportability objectives. This inquire about creates such a show by joining experiences from effective universal and residential case thinks about, master interviews with urban organizers, designers, and policymakers, and nitty gritty cost-benefit examinations. The approach points to illustrate how green rooftops can provide both quantifiable monetary returns and natural advancements, supporting China's double goals of urban supportability and carbon lack of bias by 2060.

This paper starts by looking into the multifunctional benefits of green rooftops nearby the challenges that have constrained their broader appropriation. It at that point points of interest the technique utilized in gathering and analyzing both subjective and quantitative information. Taking after this, a commerce demonstrate custom fitted for China's urban setting is proposed, emphasizing esteem creation for assorted partners. The discoveries from information investigation give prove of the model's achievability and versatility. The talk highlights the key deterrents that must be overcome and proposes key arrangement and association arrangements to empower large-scale execution. The paper concludes by sketching out future investigate bearings to encourage upgrade green roof integration into China's urban foundation.

2. Literature Review

Green rooftops have advanced from decorative housetop gardens into a basic component of feasible urban foundation. Early considers centered basically on the stylish and recreational perspectives of housetop greenery. Over time, be that as it may, inquire about has progressively recognized green rooftops as multifunctional frameworks that contribute to natural flexibility and financial productivity. Spearheading work by Oberndorfer *et al.* [2007] ^[19] and Getter and Rowe [2006] ^[10] has made a difference move the story, highlighting how green rooftops moderate urban warm islands, oversee stormwater runoff, and improve building vitality proficiency. This advancement reflects a broader move in urban arranging, where supportability and versatility are getting to be as vital as visual appeal. Environmental benefits are central to the case for green rooftops. Various thinks about have recorded their capacity to diminish surrounding temperatures, subsequently relieving the urban warm island effect—a wonder especially articulated in thickly built urban regions Berardi, [2016] ^[1]. In expansion, green rooftops make strides discuss quality by retaining toxins and sequestering carbon, contributing to generally decreases in nursery gas emanations. Their part in stormwater administration is similarly noteworthy; by holding and continuously

discharging water, green rooftops lighten the weight on urban waste frameworks and diminish surge dangers Wong *et al.*, [2003] ^[30]. Collectively, these capacities emphasize the potential of green rooftops to improve urban natural health. Economic investigations have encourage reinforced the request of green rooftops by illustrating significant vitality fetched reserve funds. Observational inquire about shows that green rooftops can diminish vitality utilization by 20-30% due to their common protection properties (Getter & Rowe, 2006; Mariner, 2008) ^[10, 17]. In expansion to bringing down operational costs, green rooftops expand the life expectancy of material materials by securing them from extraordinary climate, subsequently lessening upkeep costs and upgrading property values. Such financial benefits are basic in supporting the case for joining green rooftops into unused and existing urban structures.

Internationally, inventive commerce models have developed to back the appropriation of green rooftops. Cities like Singapore and Copenhagen have effectively executed systems that use open appropriations, charge motivating forces, and public-private associations to back green framework (Díaz *et al.*, 2017) ^[6]. These models give important case thinks about for the improvement of versatile commerce approaches custom fitted to diverse urban settings. In differentiate, the arrangement environment in China, whereas strong in a few districts, remains divided. Xu, Li, and Zhang [2018] ^[15] note that irregularities in building codes and administrative systems display noteworthy challenges for the large-scale usage of green rooftops in Chinese cities. Despite the broad body of writing on the natural and financial benefits of green rooftops, noteworthy inquire about crevices stay. Current considers have generally centered on the specialized and operational viewpoints of green roof establishments, with constrained investigation of comprehensive, versatile commerce models that coordinated both financial motivations and natural results. Besides, there is a require for encourage examination of how arrangement and administrative systems can be harmonized to bolster far reaching appropriation, especially in quickly urbanizing locales like China. In rundown, the writing uncovers that green rooftops offer a multifaceted arrangement to urban natural and financial challenges. Be that as it may, realizing their full potential requires overcoming money related, administrative, and specialized boundaries through imaginative trade models and strong approaches. This consider looks for to address these holes by proposing a comprehensive commerce demonstrate that adjusts with both national maintainability objectives and nearby urban advancement needs.

3. Methodology

This check out utilizes a consecutive blended-strategies method to assess the monetary and natural advantages of inexperienced rooftops and to create a trade reveal custom-made to urban conditions in China. By joining both subjective and quantitative statistics series and research techniques, the contemplate offers a comprehensive assessment of the ability commitments of green rooftops to maintainable urbanization. This technique lets in for a all-encompassing understanding of the inquire approximately trouble by using initially investigating subjective studies and at that factor approving them with quantitative data Creswell & Plano Clark, [2018] ^[5]. The approach

accommodates of 4 key components: Inquire approximately Plan, Information Collection, Information Examination, and Validation.

3.1 Research Design

The consecutive mixed-strategies method became chosen to coordinate each subjective and quantitative information, guaranteeing a well-rounded understanding of the point. This inquire approximately plan permits for an beginning research of wide subjects through subjective techniques, taken after by means of numerical information collection for

actual approval Plano Clark & Ivankova, [2016]. The subjective thing includes the make use of case ponders and associate interviews to offer in-depth reports into inexperienced roof selection in numerous city settings. The quantitative aspect comprises of organized overviews and auxiliary facts examination, which offer quantifiable show to reinforce the subjective discoveries. This combination ensures that the ponder captures each subjective factors of view and goal cash related and herbal impacts of inexperienced rooftops.

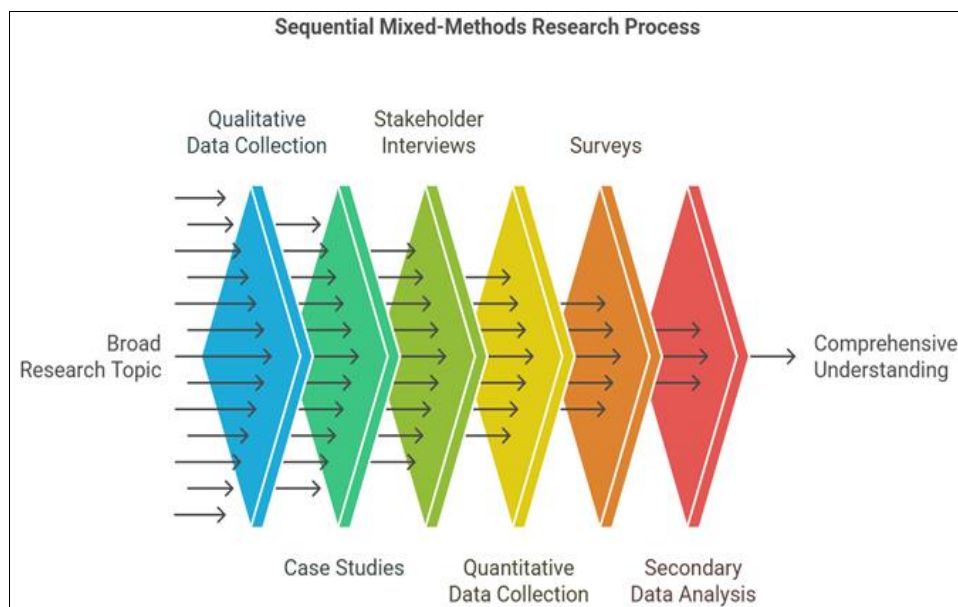


Fig 1: A visual representation of the sequential mixed-methods research design, incorporating qualitative data collection, stakeholder interviews, surveys, and secondary data analysis to refine a broad research topic.

3.2 Data Collection

The data collection process was structured into three main phases, each targeting different aspects of green roof

implementation. The three key data collection methods used in this research are Case Studies, Stakeholder Interviews, and Surveys and Secondary Data

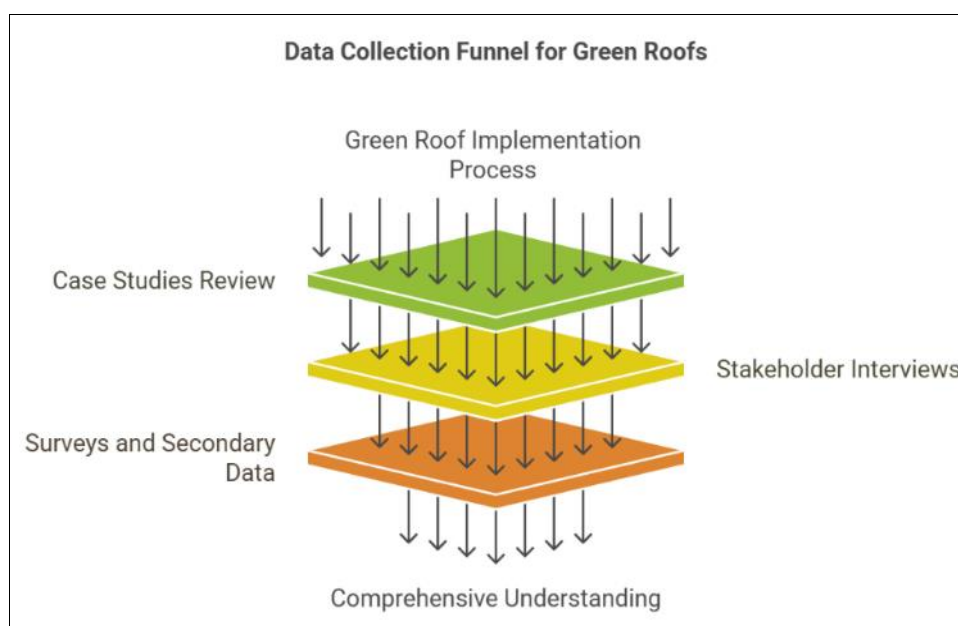


Fig 2: Step-by-step Funnel Chart of the data collection process, using case study reviews, stakeholder interviews, and surveys/secondary data for green roof research.

For the case studies, the research focuses on successful green roof projects conducted in cities known for their urban sustainability initiatives, including Singapore, Copenhagen, and select Chinese urban centers. These cities were selected since they may be global pioneers in executing green foundation and feature urban situations that intently take after those in China. The case studies focused on the energy savings achieved through reduced cooling and heating costs, cost reductions in building maintenance and stormwater management, environmental benefits such as improved urban biodiversity and carbon sequestration, and the challenges faced during the implementation of green roofs, such as regulatory constraints and financial feasibility. These illustrations had been important in giving training for adjusting green roof preparations to the Chinese urban setting Tan *et al.*, [2014]; Oberndorfer *et al.*, [2007]^[19, 26].

In addition to the case studies, semi-structured interviews had been carried out with a unique bunch of companions, counting city organizers, property engineers, government, and supportability experts. The purpose of these interviews was to bring together all the way down to earth studies at the demanding situations of actualizing green rooftops, the a part of preparations and motivating forces, and the monetary blessings and lengthy-term maintainability of green rooftops. These interviews too looked for to distinguish visible obstructions to a ways reaching appropriation and the seeds of partners on how these boundaries may be overcome. The semi-dependent nature of the interviews approved for open-ended reactions while nonetheless

ensuring that the discussions remained focused on the key subjects of the contemplate Bryman, [2016]^[3]. The subjective data from the interviews were recorded, deciphered, and analyzed using topical examination to apprehend repeating designs and insights.

To inspire enhance the records, quantitative statistics were collected through studies conveyed to assets supervisors and building owners who have as of now accomplished green rooftops. These research had been planned to bring together information on power utilization, renovation costs, go back on project (ROI), and payback durations for green roof establishments. The evaluation reactions given important statistics at the cash associated guidelines of inexperienced roof establishments and their versatility capacity. In expansion to the vital records, auxiliary records sources consisting of scholarly diary articles, government reviews, and industry distributions have been advised to provide greater bits of information into the prices, benefits, and demanding situations of green roof execution. This auxiliary fact complemented the critical look at discoveries, advertising an extra comprehensive understanding of the problem Carter & Keeler, [2008]^[4].

3.3 Data Analysis

The information exam handle created from two unmistakable additives: topical investigation for subjective records and fee-gain investigation (CBA) for quantitative information.

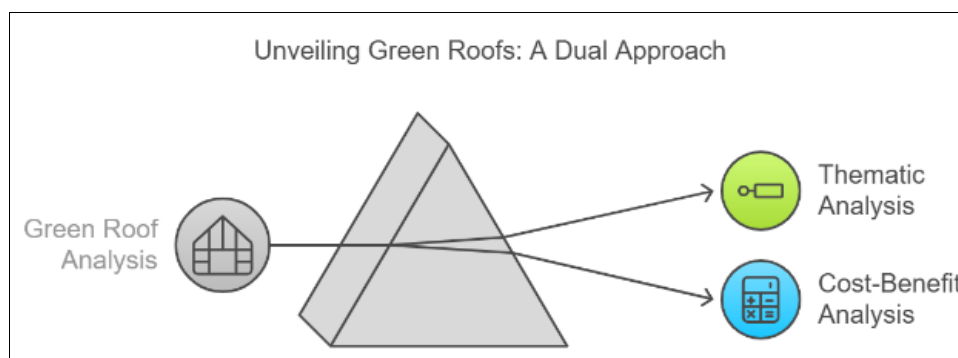


Fig 3: Conceptual Diagram of the Dual Approach to Green Roof Analysis, illustrating the integration of Thematic Analysis and Cost-Benefit Analysis.

For the subjective data collected from the case thinks approximately and partner interviews, topical exam was utilized to apprehend common subjects, designs, and studies. Topical research accepted for the investigation of topics which include administrative barriers to inexperienced roof appropriation, the a part of authorities motivating forces and technique returned, and the visible economic and herbal benefits of inexperienced rooftops. This exam made a difference understand repeating demanding situations, which include the want of mindfulness and faulty judgments approximately the lengthy-term monetary advantages of inexperienced rooftops. It moreover given bits of expertise into how social, budgetary, and administrative variables would possibly have an impact on the choice of inexperienced rooftops in the Chinese placing Braun & Clarke, [2006]^[2]. For the quantitative facts, a cost-gain investigation (CBA) was

performed to examine the budgetary advantages of inexperienced rooftops (e. G., vitality funding price range, expanded belongings values, and dwindled protection charges) with the introductory speculation costs and continuous operational expenses. Factual devices had been utilized to calculate ROI and decide payback intervals for green roof institutions over special building types and urban settings. This exam too included comparative measurements to survey power usage and maintenance fees in homes with and without green rooftops. The comes approximately of the CBA were displayed making use of visible helps inclusive of charts and tables to offer help define key discoveries and encourage translation Ting *et al.*, [2020]^[27].

3.4 Validation

To ensure the robustness and reliability of the research findings, several validation techniques were employed:

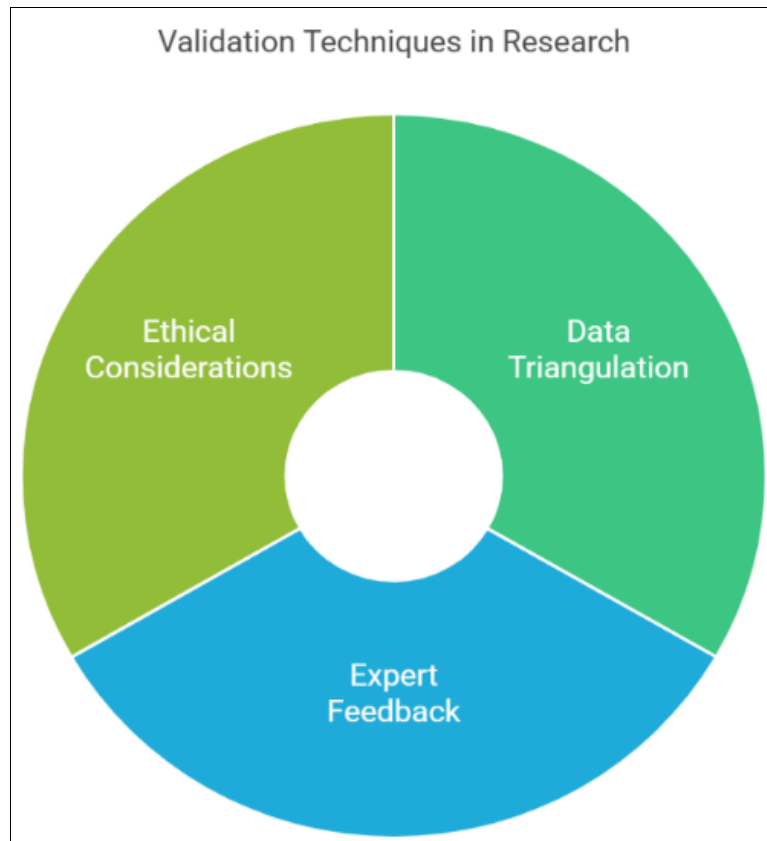


Fig 4: Circular Diagram representing Validation Techniques, showing the components: Ethical Considerations, Data Triangulation, and Expert Feedback

Data triangulation was used to cross-verify findings across multiple data sources. The qualitative data from the interviews were compared with the quantitative survey data to ensure consistency and validity. Furthermore, the case study data were cross-referenced with survey responses to validate the conclusions drawn from both qualitative and quantitative research Patton, [1999] ^[22]. Expert feedback was solicited from professionals in the field of urban sustainability and green infrastructure. These experts reviewed the preliminary findings and business model, providing valuable insights to help refine the research and ensure that it was both theoretically sound and practical Ghauri & Grønhaug, [2020] ^[8]. Finally, strict ethical guidelines were followed throughout the research process. All participants in the interviews and surveys were informed about the purpose of the research, and their consent was obtained before participation. Additionally, all personal data was anonymized to maintain confidentiality and ensure compliance with ethical standards Resnik, [2020] ^[23].

4. Business Model Development

The proposed business model for green roofs aims to transform underutilized rooftops into energy-efficient, environmentally beneficial spaces while creating a sustainable and scalable solution for urban environments in China. By leveraging the advantages of green infrastructure, this business model combines economic viability with significant environmental impact. Central to the business model is the introduction of an e-commerce platform to facilitate the installation and ongoing management of green roofs, making it easy for potential customers to access information, request quotes, and monitor the performance of their green roof systems.

4.1 Value Proposition: The core value proposition of the business is the transformation of underutilized rooftops into multifunctional, energy-efficient spaces that offer a variety of environmental and economic benefits. This includes mitigating the urban heat island effect, reducing energy consumption, enhancing air quality, and improving stormwater management. For property owners and businesses, green roofs also increase the lifespan of building infrastructure and offer potential for property value appreciation. By offering these benefits through a streamlined e-commerce platform, the business will also provide convenient access to services such as consultation, design, installation, and maintenance of green roofs.

4.2 Customer Segments: The business model targets multiple customer segments, including real estate developers, property owners, industrial and commercial building managers, government agencies, and the general public. Real estate developers can enhance property value and attract environmentally conscious tenants by integrating green roofs into their buildings. Property owners, including those managing residential, commercial, and mixed-use spaces, benefit from long-term energy cost savings and improved urban livability. Industrial and commercial building managers, particularly those overseeing large rooftop spaces, can optimize energy efficiency and reduce heating and cooling expenses. Government agencies play a key role in promoting green roofs as part of their sustainability and climate action strategies, using them to mitigate urban heat islands and support carbon neutrality goals. Additionally, the general public can engage with the business through its e-commerce platform, accessing

information, resources, and small-scale green roof installations for residential properties, contributing to broader urban greening efforts.

4.3 Income Streams: The business model's critical revenue streams include establishment expenses, maintenance contracts, energy savings sharing, carbon credits, and government subsidies.

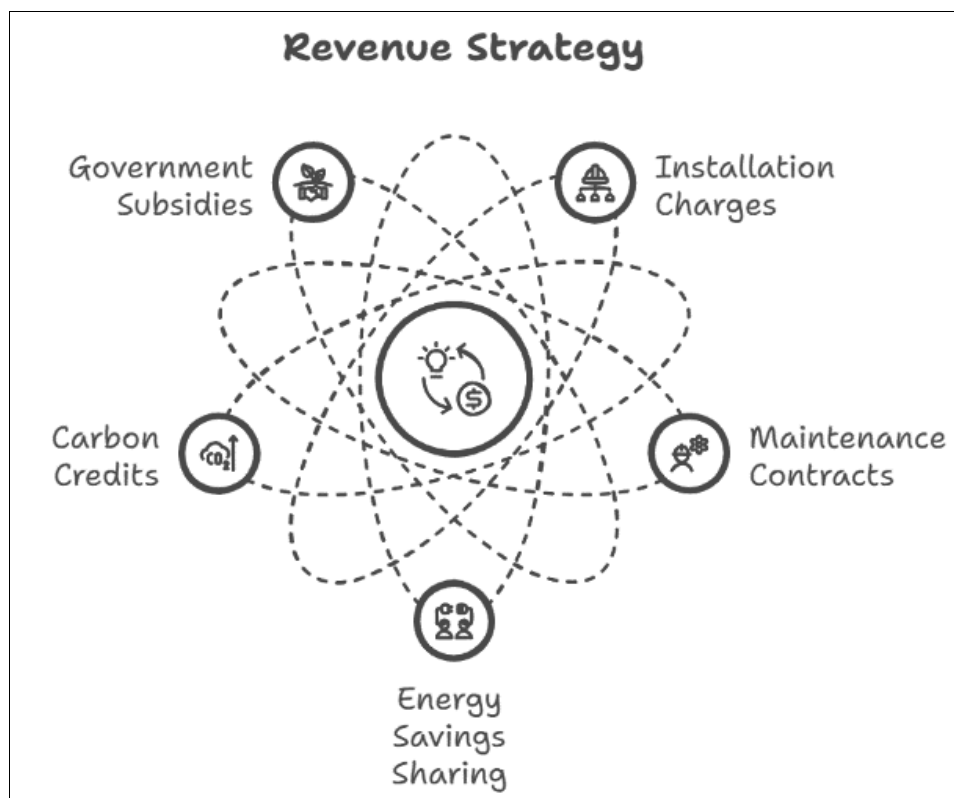


Fig 5: Conceptual Model of Revenue Strategy, illustrating the interconnectedness of key elements through a Network Diagram.

Clients will be charged for the installation of green rooftops, covering design, planning, and construction services, with costs varying based on building size and project complexity. Long-term maintenance contracts will generate steady revenue while ensuring the green roofs continue providing environmental and energy-saving benefits through regular inspections, plant care, and system upgrades. Additionally, the company will adopt a performance-based earnings model by sharing a portion of the energy savings from reduced heating and cooling costs with clients, ensuring mutual benefits. Another revenue stream comes from carbon credits, as the business can participate in carbon trading programs by reducing the carbon footprint of urban buildings. Finally, the company will seek financial support from government sustainability initiatives, including green building grants, tax incentives, and subsidies for eco-friendly projects.

4.4 Cost Structure

The price shape of the enterprise consists of each fixed and variable prices, protecting preliminary capital funding, ongoing operational expenses, technological development, and marketing prices. The startup phase would require sizeable investment in infrastructure, such as materials for inexperienced roof installations such as flora and waterproofing structures, as well as system and generation for the e-trade platform. The predicted value for shopping materials for set up, which include flowers, irrigation structures, and water-proof membranes, is approximately ¥500,000-¥800,000. Additionally, generation and platform

improvement fees for the e-commerce machine are projected to be around ¥three hundred, 000. Research and development expenses to optimize installation techniques and beautify provider offerings are expected to require an initial allocation of ¥200,000. Ongoing operational expenses will include staffing for venture management, customer support, and sales teams, if you want to require an anticipated ¥50,000 in keeping with month in salaries and wages. Office space condominium and utilities are projected to value approximately ¥20,000 according to month, while preservation and system servicing will upload every other ¥30,000 consistent with month. Investments in technology will be important for managing installations and services effectively, tracking patron orders, measuring performance metrics, and tracking electricity savings and environmental impact. Continuous updates to the e-commerce platform to satisfy person needs would require a predicted ¥100,000 annually for software program upkeep and improvements. Marketing costs will attention on virtual advertising, brand development, and outreach tasks to attract both business and home customers, with an initial advertising price range of ¥250,000 allocated to online campaigns, public family members, and partnership applications. Strategic collaborations with creation companies, authorities entities, and environmental businesses may be critical for scaling the enterprise and expanding the client base. As the employer grows, reinvestment in expansion efforts, new product tendencies, and marketplace penetration strategies can be vital to preserve lengthy-time period profitability and make certain significant adoption of green roofs across China.

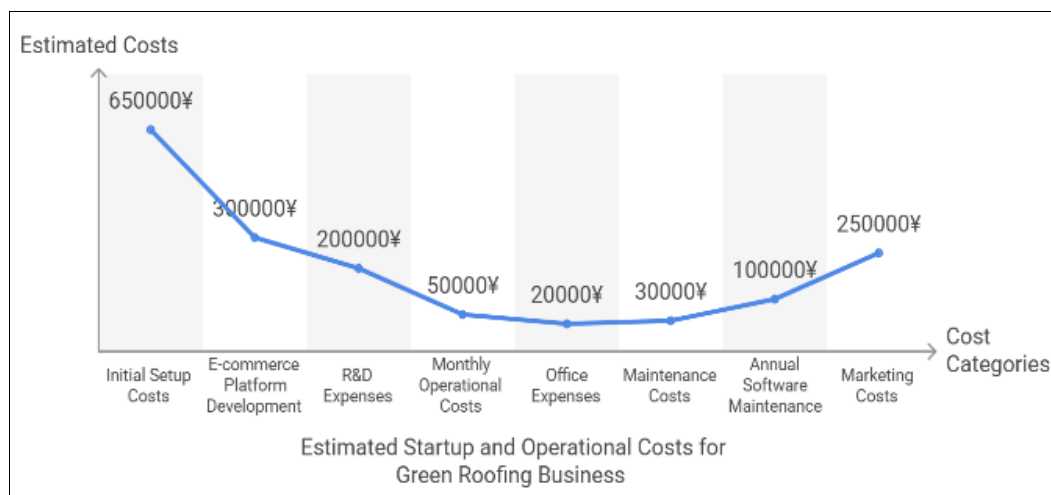


Fig 6: Line Graph of Estimated Startup and Operational Costs for Green Roofing Business, illustrating cost variations across different categories.

4.5 Implementation Roadmap

The usage of the unpracticed roof trade display will boost in 3 levels, beginning with the Pilot Organize, where a choose number of pilot wanders might be embraced to illustrate the trade's capability in green roof plan and basis, permitting for refinement of documentation, evaluation of specialised achievability, and recognizable proof of starting demanding situations. Taking after powerful pilot ventures, the Improvement arrange will center on scaling operations by using developing into larger urban areas, pulling in a broader client base, forces selling endeavors, and reinforcing associations with key companions. At ultimate, the Full-Scale Commercialization arrange will encompass the vast usage of green housetops over non-public, commercial, and mechanical homes, went with the aid of the improvement of the e-trade stage to provide a steady and user-friendly interface for customers to fasten in with the advertised administrations.

4.6 Scalability and Sustainability

The adaptability of the commerce exhibit lies in its capability to grow over distinctive city facilities in China and past. As the showcase for possible basis develops, the trade display may be adjusted to different districts with comparable urbanization styles and herbal demanding situations. The key to long-term maintainability might be keeping up stable institutions, optimizing operations, and consistently progressing the green roof services to modify with advancing showcase needs. Moreover, the reveal will advantage from economies of scale because it develops, decreasing establishment expenses and expanding benefit. Overcoming obstacles such as tall starting capital costs and administrative boundaries will require collaboration with policymakers and the proceeded development of resourceful inexperienced advances.

5. Analysis and Findings

The investigation of this inquire about combines quantitative and subjective information to survey the ability of green rooftops as a viable arrangement for urbanization in China. The quantitative exam centers on the cash associated

angles of inexperienced rooftops, counting vitality reserve funds, go back on speculation (ROI), and payback durations, whereas the subjective exam offers experiences into the feasible challenges and openings for green roof utilization, as accumulated through associate interviews and case ponders. The mixture of those discoveries offers a comprehensive evaluation of the trade display and its potential for scalability.

5.1 Quantitative Analysis

The quantitative examination normally makes a speciality of the fee-benefit evaluation (CBA) of inexperienced roof installations, comparing the economic viability of the proposed business model through analyzing key metrics inclusive of power financial savings, go back on investment (ROI), and payback durations across residential, commercial, and commercial houses. Energy savings had been assessed with the aid of comparing the electricity intake of buildings with and without green rooftops, revealing that green roofs can lead to power financial savings of 20-30%, with sizeable discounts in cooling energy use throughout summer and lower heating needs in winter, in particular reaping rewards commercial homes because of their larger roof regions. ROI calculations considered set up costs, which includes substances, hard work, and layout, against long-time period savings from decreased energy consumption, improved belongings value, and lower preservation charges, displaying that business homes done an ROI of 15-20% yearly, at the same time as residential buildings had a lower ROI of 10-15%, reflecting their highly lower power demands and assets price appreciation. Payback durations, defined as the time required to recover preliminary investments via financial savings and elevated belongings fee, averaged 6-8 years for residential homes and a shorter 5-7 years for business and commercial residences, demonstrating that inexperienced roofs offer a especially quick go back on investment, specifically for larger industrial and commercial systems. The specific results of the cost-benefit analysis, including strength savings, ROI, and payback periods, are summarized in Table 1 underneath

Table 1: Cost-Benefit Analysis Summary

Building Type	Energy Savings (%)	ROI (%)	Payback Period (years)
Residential	20	12	7
Commercial	25	18	6
Industrial	30	22	5

The analysis clearly shows that green roofs offer substantial financial returns, particularly for commercial and industrial buildings, where the combination of energy savings and increased property values leads to quicker payback periods.

5.2 Subjective Analysis

The subjective analysis become primarily based on stakeholder interviews and case studies, which supplied treasured insights into the demanding situations and possibilities related to green roof adoption in urban China. Interviews with urban planners, belongings developers, and government officers revealed that regulatory guide and authorities incentives are vital for the considerable adoption of green roofs. However, high initial expenses and inadequate infrastructure for green roof installations had been recognized as massive limitations. Urban planners highlighted that while green roofs align with sustainability dreams, policy uncertainty and the dearth of monetary incentives in positive regions stay hindrances to massive-scale implementation (Liu & Zhao, 2022) ^[16]. Property builders emphasised that go back on investment (ROI) and energy financial savings are principal drivers for adopting inexperienced roofs, although they also raised concerns about maintenance charges and lengthy-time period viability, mainly in regions with extreme weather situations (Wang & Li, 2021) ^[28]. Despite these demanding situations, stakeholders agreed that the long-term environmental and economic blessings outweigh the initial expenses and issues. Case studies from Singapore and Copenhagen further illustrated a hit green roof integration thru public-non-public partnerships and government rules that incentivize sustainable infrastructure. In each towns, green roofs extensively reduced urban warmth islands, advanced air best, and supplied significant strength financial savings (Tan *et al.*, 2023; Jensen *et al.*, 2020) ^[12, 26], assisting the case for their adoption in Chinese cities. These worldwide examples had been used to perceive fine practices and provide a strategic roadmap to conquer regulatory and monetary limitations in urban China.

5.3 Integration of Findings

The mixture of quantitative and subjective statistics offers a comprehensive understanding of the capability for green rooftops to make a contribution to viable urbanization in China. The value-gain investigation illustrates that green rooftops can provide critical cash associated returns via power funding finances, accelerated belongings values, and diminished operational fees, with fairly brief payback periods. These discoveries bolster the possibility of actualizing inexperienced rooftops in city settings, mainly for industrial and mechanical houses. The accomplice interviews and case thinks about spotlight the importance of government lower back and money associated motivating forces in encouraging the far attaining appropriation of green rooftops. In spite of the truth that challenges together with tall beginning costs and aid worries stay, the fine herbal affect and the capacity for lengthy-time period investment price range make a solid trade case for

inexperienced rooftops. The customary case ponders furthermore offer worthwhile stories into how association changes, endowments, and motivating forces can triumph over financial boundaries and invigorate call for. By combining those discoveries, the inquire approximately affirms that the proposed commerce reveal for inexperienced rooftops is each financially reasonable and certainly positive, with the potential for adaptability over exclusive city settings. The choice of inexperienced rooftops can provide assistance China meet its supportability objectives by using lessening vitality utilization, upgrading city livability, and contributing to carbon lack of bias. The proposed trade display no longer because it had been addresses modern obstructions but moreover leverages openings for public-non-public institutions, authorities bolster, and the growing request for green framework.

6. Challenges and Limitations

Despite of the numerous monetary and natural advantages of inexperienced rooftops, some demanding situations damage their a long way reaching appropriation and versatility, especially in China. These demanding situations span financial imperatives, operational and guide challenges, administrative and auxiliary obstructions, and companion hesitance. Understanding and tending to these confinements is crucial for the fruitful usage of inexperienced rooftops as an affordable thing of feasible city development.

6.1 Financial Barriers

One of the most noteworthy impediments to inexperienced roof choice is the tall beginning fetched of established order. The usage of green rooftops requires a incredible forthright mission in materials together with waterproof films, water gadget frameworks, and flowers, at the side of labor and plan mastery Li and Zhang ^[15]. This monetary burden is particularly prohibitive for little property owners and corporations which can want get to to good enough capital. Whereas green rooftops produce lengthy-term reserve budget via decreased energy usage, multiplied roof lifestyles expectancy, and advanced assets values, the starting expenses often save you project Nguyen and Le ^[18]. Although government appropriations and cash related motivating forces exist in positive districts, their accessibility and scope exchange widely. A few districts deliver awards or price credits for green roof establishments, whereas others provide small to no budgetary assist, making aberrations in choice quotes over exclusive urban zones Xu, Li, and Zhang ^[15]. Moreover, severa motivation applications are transitory or challenge to association modifications, making them untrustworthy for lengthy-term hypothesis arranging. Lacking cash related bolster at each metropolitan and countrywide ranges worsens the mission, specifically in towns wherein foundation advancement competes with different squeezing budgetary concerns.

6.2 Maintenance and Operational Challenges

Beyond the start established order, progressing support

conditions posture another fundamental project for inexperienced roof appropriation. Not in any respect like regular housetops, green rooftops require ordinary care to assure the wellbeing of plants, assume bother invasions, and preserve up suitable seepage frameworks. Basic help assignments comprise water device, pruning, ordinary plant substitution, and intermittent simple critiques to guarantee the roof stays in ideal circumstance (Patel and Kumar) ^[20].

For property owners and workplace supervisors, these repeating protection costs can gotten to be burdensome, specially in high-upward push homes or locales with remarkable weather conditions wherein plant survival costs trade. Moreover, disgraceful help can result in water renovation troubles, root abundance, and framework disappointments, lessening the proficiency and existence span of inexperienced roof establishments Stop and Lee ^[25]. The specialized mastery required for retaining up green rooftops is too a proscribing calculate. Not at all like ordinary rooftops, which require negligible oversight, green rooftops require data of cultivation, waste designing, and basic astuteness, making them more complicated to supervise without specialized getting ready or proficient offerings. Without directly available and reasonable renovation preparations, green rooftops threat being dismissed, driving to execution disintegration and expanded expenses through the years. In this manner, coordination robotized water system frameworks, advancing low-maintenance plant species, and advertising sponsored guide administrations may also offer assistance lighten those operational limitations.

6.3 Regulatory and Basic Limitations

The administrative environment encompassing inexperienced roof appropriation in China stays conflicting, assist complicating their usage. Whereas a few cities have constructed up approaches that empower or certainly order green rooftops on unused homes, severa locales want clear regulations, standardized conditions, or requirement devices Li, Chen, and Xu ^[14]. This administrative uncertainty makes vulnerability for designers and assets proprietors who can be inquisitive about receiving green roof innovation however are averted through the need of valid clarity and procedural complexity.

Structural confinements show any other task, specially for present homes that have been now not mentioned to returned the extra weight and water maintenance capacity required for green rooftops. Retrofitting those buildings frequently requires wide auxiliary fortifications, expanding each fees and calculated troubles Zhao, Shen, and Chen ^[34]. Numerous greater pro non-public and industrial buildings in China do not meet the designing guidelines essential to in shape green roof establishments, making massive-scale retrofitting infeasible without sizable budgetary and specialized help.

Furthermore, divided arrangement requirement implies that certainly wherein inexperienced rooftops are empowered, motivation systems, permitting forms, and compliance checking live frail. Without clear commands or financial motivations to counterbalanced retrofitting charges, property owners may additionally see small concept to are searching for after inexperienced roof ventures. Tending to those limitations calls for facilitated country wide and

metropolitan strategies that give consistent controls, streamlined endorsement paperwork, and robust budgetary components to encourage huge adoption.

6.4 Stakeholder Appropriation and Awareness

The powerful integration of inexperienced rooftops into city framework is intensely subordinate at the discernment and eagerness of key partners, counting belongings engineers, constructing directors, policymakers, and inhabitants. One of the vital challenges in companion appropriation is the want of mindfulness and understanding with admire to the economic and natural advantages of green rooftops Garcia and Rodriguez ^[9].

Many designers prioritize short-term fetched investment budget over lengthy-time period maintainability, choosing for conventional material frameworks because of their lower starting costs. Furthermore, assets proprietors may additionally see green rooftops as non-important fashionable will increase or maybe than useful basis improvements which could improve energy effectiveness and building esteem Huang, Zhang, and Chen ^[11]. Moreover, inhabitant and inhabitant buy-in may be a simple calculate. Whereas inexperienced rooftops give communal benefits including progressed speak satisfactory, clamor lessening, and fashionable development, they will furthermore present issues about upkeep charges, auxiliary protection, and availability. Overcoming these issues calls for focused on instructive campaigns, show ventures, and simple fee-benefit examinations that absolutely communicate the long-term choices of green roofs. Additionally, skepticism with recognize to the return on venture (ROI) and long-time period solidness of green rooftops stays a vital boundary. Numerous property proprietors are reluctant to make contributions in new improvements without clear prove in their cost-effectiveness and unwavering great Huang, Zhang, and Chen ^[11]. To address this project, policymakers and industry pioneers ought to paintings collectively to present complete case thinks about, execution statistics, and pilot packages that grandstand fruitful usage and cash associated benefits. Additionally, skepticism regarding the return on investment (ROI) and long-term durability of green roofs remains a significant barrier. Many property owners are hesitant to invest in unfamiliar technologies without clear evidence of their cost-effectiveness and reliability Huang, Zhang, and Chen ^[11]. To address this challenge, policymakers and industry leaders must work together to provide comprehensive case studies, performance data, and pilot programs that showcase successful implementations and financial benefits.

6.5 Overcoming Challenges for Large-Scale Implementation

To inspire the large-scale appropriation of inexperienced rooftops in China, a comprehensive and multi-pronged manner is required to cope with the budgetary, administrative, operational, and stakeholder-related challenges that save you their vast execution. By coordination budgetary lower back additives, administrative modifications, progressed renovation techniques, open education sports, and studies-pushed show ventures, China can viably scale up inexperienced roof appropriation and maximize its natural and financial benefits.

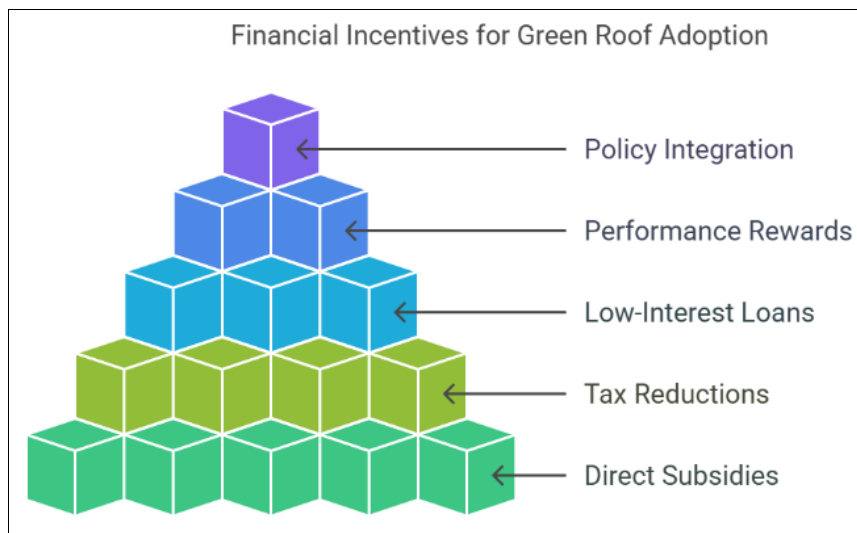


Fig 7: Layered Pyramid Diagram outlining Financial Incentives, demonstrating the hierarchy of incentives for Green Roof Adoption.

One of the most noteworthy obstructions to green roof selection is the tall forthright taken a toll of establishment. Numerous property owners, designers, and corporations falter to make contributions in green rooftops due to the full-size starting expenses associated with substances, exertions, and auxiliary changes (Li and Zhang ninety six) [15]. Whereas lengthy-term energy reserve budget and expanded belongings values can balanced those charges, the want of brief cash associated returns debilitates appropriation Nguyen and Le [18]. To deal with this, the Chinese government ought to execute a prepared budgetary motivating force framework, counting coordinate endowments that lessen starting capital expenses, as seen in towns like Toronto and Berlin, in which money associated help covers 30-50% of status quo prices Xu, Li, and Zhang [15]. Property fee diminishments for homes with inexperienced rooftops can too empower engineers and property supervisors to make a contribution in viable basis Stop and Lee [25]. Also, government-backed inexperienced financing packages, including low-hobby advances or 0-hobby credit strains, can provide assistance assets proprietors oversee status quo fees extra viably Garcia and Rodriguez [9]. Performance-based motivating forces that remunerate homes undertaking noteworthy energy reserve budget, carbon sequestration, or stormwater management proficiency can help energize speculation in green foundation Huang, Zhang, and Chen [11]. Adjusting money related motivations with broader weather approaches will make a financially affordable pathway for huge-scale inexperienced roof appropriation in China.

The nonappearance of regular controls and divided method authorization has altogether avoided the broad choice of green rooftops in China Li, Chen, and Xu [14]. Whereas some districts provide monetary bolster or commands, others want clear rules on inexperienced framework development. Building up a throughout the state technique machine is fundamental to assure that each one districts have standardized constructing codes, compliance requirements, and cash associated motivations. Cities must implement constructing code necessities that command green rooftops for unused non-public, commercial, and mechanical buildings, corresponding to techniques in France and Switzerland, in which inexperienced rooftops are legitimately required for specific structures (Zhao, Shen,

and Chen) [34]. To deal with the venture of greater pro buildings missing auxiliary lower back, sponsored retrofitting programs have to be offered to help assets owners in adjusting current systems to suit inexperienced rooftops (Díaz, Pérez, and Torres 35) [6]. Green roof requirements need to too be joined into metropolitan supportability plans to guarantee that future city improvement includes inexperienced framework as a crucial factor of city arranging Wong, Olesen, and Hesselbjerg [31]. A countrywide green roof certification program, comparative to LEED (Authority in Vitality and Natural Plan), have to be offered to give official accreditation for engineers who execute excessive-overall performance inexperienced rooftops (Patel and Kumar 46) [20]. Building up administrative consistency and streamlining compliance techniques will increment speculator certainty and boost the regular integration of inexperienced rooftops into urban advancement strategies.

The long-term adequacy of inexperienced rooftops depends on suitable upkeep and operational administration. Numerous belongings proprietors are debilitated with the aid of the repeating charges and specialized mastery required for preservation Talk *et al.* To overcome this obstruction, governments ought to deliver budgetary assist for progressing help fees, counting water machine, bother manipulate, and plant substitution Xu, Li, and Zhang [15]. Empowering the utilize of neighborhood and drought-resistant plant species can provide assistance lessen water machine wishes, lower preservation charges, and guarantee long-time period supportability of green rooftops Nguyen and Le [18]. Building up gifted preparing publications for office supervisors, scene designers, and urban organizers will grow the talent required for preserving up green rooftops productively Garcia and Rodriguez [9]. Moreover, coordination sensor-based totally water gadget frameworks, farther checking gadgets, and AI-pushed plant wellbeing investigation can optimize preservation productivity and decrease operational fees Huang, Zhang, and Chen [11]. Contributing in mechanical progressions and preparing packages will guarantee that inexperienced rooftops stay reasonable and feasible in the long time.

One of the greatest obstructions to green roof extension is moo open mindfulness and partner skepticism Johnson [13]. To power open engagement and speculator actuality,

centered on training sports ought to be provided to highlight the monetary and natural advantages of inexperienced rooftops. Media campaigns using television, social media, and print media can exhibit effective case ponders and increment mindfulness of green roofs' component in maintainability Wang and Yang ^[29]. Open workshops, city greening expos, and show off visits can improve educate groups about the focal factors of green rooftops Smith and Brown ^[24]. Empowering commercial authentic area engineers to execute inexperienced rooftops by marketing open acknowledgment, supportability presents, and assess advantages can encourage incentivize choice Oberndorfer *et al.* ^[19]. Joining forces with schools and schools to coordinated green roof check out, making ready, and understudy ventures can domesticate long-term dedication to green framework Mariner ^[17]. Raising open mindfulness and locks in key companions will quicken the acknowledgment and appropriation of inexperienced roofs.



Fig 8: Architectural Visualization of a Future Green City, showcasing buildings with lush rooftop vegetation and solar energy integration.

Scientific inquire about and real-international show ventures are essential for approving the economic achievability of green rooftops and demonstrating their lengthy-time period advantages to economic professionals, designers, and policymakers. Numerous partners waver to embrace green rooftops because of a want of experimental records

displaying their return on hypothesis (ROI) and execution measurements. To address this assignment, large-scale display green rooftops ought to be actualized in key city facilities to produce real-time records on vitality reserve price range, carbon decrease, and urban cooling influences (Dunnett and Kingsbury) ^[7]. Building up institutions between authorities businesses, faculties, and private undertakings will inspire statistics-pushed inspect thinks approximately on money associated funding funds, biological advantages, and social influences of green rooftops (Huang, Zhang, and Chen) ^[11]. Conveying IoT-based herbal sensors to degree temperature lessening, discuss pleasant advancements, and stormwater assimilation fees could make a information shop to be had to policymakers and engineers Wong, Gorgulu, and Li ^[30]. Extending investigate to specific topographical locales will provide help analyze how numerous climates have an effect on inexperienced roof execution and understand best plant species and status quo techniques Xu, Li, and Zhang ^[15]. By coordination cash associated motivating forces, administrative changes, renovation bolster, open mindfulness sports, and research-pushed approval, China can overcome obstructions to massive-scale inexperienced roof execution. These methodologies will not because it have been improve city supportability however moreover alter with national carbon nonpartisanship targets and global natural commitments. If as it should be actualized, green rooftops can play a transformative component inside the destiny of China's cities, making robust, energy-green, and first rate urban situations.

7. Approach Suggestions and Recommendations

To efficaciously execute the green roof alternate show in China and other city zones, stable administrative bolster, collaborative institutions, and important structures are pivotal. The taking after approach pointers and pointers are fundamental for overcoming modern obstructions and cultivating the far accomplishing appropriation of green rooftops as a sensible urban basis answer.

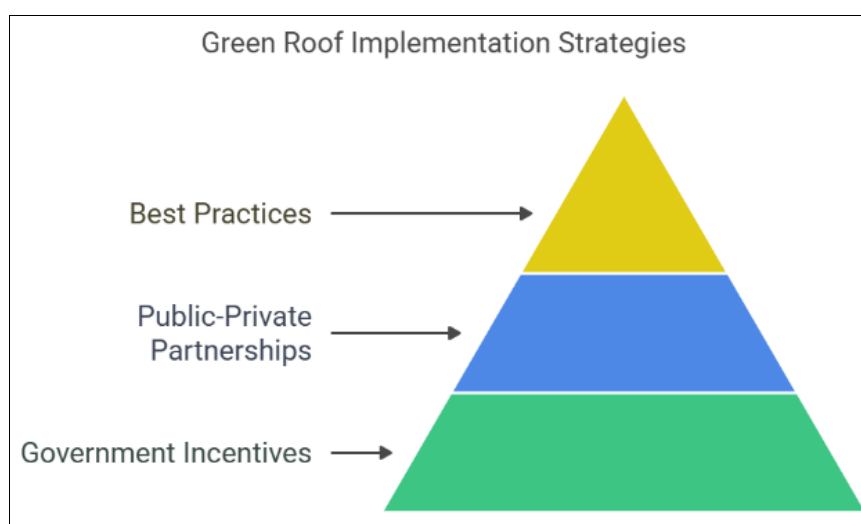


Fig 9: Layered Pyramid Diagram of Green Roof Implementation Strategies, showing the hierarchy of approaches.

7.1 Government Incentives

One of the critical impediments to the far reaching appropriation of green rooftops is the tall introductory establishment fetched. To slight this money related

assignment, the Chinese government have to gift endowments, assess motivations, and different budgetary again components specially pointed at advancing green framework. For case, giving coordinate endowments to

assets owners or engineers who introduce green rooftops might basically diminish the forthright charges, making inexperienced rooftops extra reasonable and attractive. In enlargement to coordinate budgetary motivations, determine breaks seem be marketed to property owners who embody green rooftops, which include faded belongings expenses for homes with inexperienced basis. This could serve as a long-time period motivation, adjusting financial benefits with natural objectives. Besides, the government have to furthermore don't forget advertising vitality credits or carbon credit for inexperienced roof ventures that altogether decrease energy usage or make a contribution to carbon sequestration. Supportive administrative adjustments are moreover important to installation clear hints for green rooftops. Governments should actualize constructing codes that allow or certainly empower inexperienced rooftops as part of low-priced city arranging. These controls must incorporate arrangements for the auxiliary judgment of buildings to reinforce inexperienced rooftops, in addition to guidelines for his or her plan, established order, and assist. Besides, towns should gift zoning arrangements that incentivize the incorporation of green rooftops in each modern and current buildings, mainly in zones confronting tall stages of talk infection or those inclined to the city warm island impact.

7.2 Public-Private Partnerships

The fruitful execution of inexperienced rooftops requires collaboration among open and personal phase companions. Setting up public-non-public associations (PPPs) can viably combine the qualities of each sectors—government bolster and personal department advancement. For example, nearby governments may also collaborate with true bequest designers, property proprietors, and transient people to execute inexperienced roof ventures, making sure that open arrangement adjusts with promote it incentives.

Government agencies may additionally moreover inspire institutions among non-public businesses focusing on inexperienced roof establishment and innovation providers to provide assistance decrease costs and progress the productivity of those frameworks. Also, financial teach might play a key element via marketing low-hobby advances or financing choices for assets engineers and building owners who want to contribute in green infrastructure.

At the nearby degree, districts seem collaborate with scholarly train and concrete organizers to conduct pilot ventures and showcase locales for inexperienced rooftops. These locales might show off the possibility and viability of green rooftops in tending to city demanding situations, in this way elevating mindfulness and cultivating appropriation. Public-private institutions might also moreover boost the sharing of data on power funding funds, natural affect, and the long-time period blessings of green rooftops, which might assemble agree with and energize extra companions to get concerned.

7.3 Best Hones and Vital Frameworks

To assure that green rooftops can be effectively actualized in towns beyond the beginning pilot ventures, first-class hones and key systems need to be built up. To start with and preeminent, arrangement systems need to middle on standardizing inexperienced roof establishments, ensuring consistency in plan, support, and execution over exclusive

locales. This may include putting in place clean guidelines for the sorts of flora which are reasonable for exceptional weather zones in China, in addition to the specialized details for the establishment of inexperienced roof systems. Cities over China can study from international case considers, including Singapore's Green Arrange and Copenhagen's climate adjustment techniques, each of which have effectively coordinates inexperienced framework into urban development. These cities have made robust structures for executing inexperienced rooftops thru key arranging, budgetary motivating forces, and instructive campaigns. Additionally, Chinese cities can tailor those models to their declare city wishes and challenges. In expansion to authorities-led activities, the advancement of open mindfulness campaigns is critical to empowering the appropriation of green rooftops. Instructive programs for each partners (including genuine bequest designers, belongings owners, and concrete organizers) and the not unusual open may highlight the herbal and financial advantages of green rooftops, making a difference to conquer misinterpretations and skepticism encompassing the technology.

Finally, checking and evaluation frameworks have to be set up to music the advance of green roof ventures. These frameworks would deliver actual-time statistics on power reserve budget, natural have an effect on, and the in preferred adequacy of the green rooftops in progressing city supportability. By gathering and reading this statistics, towns can refine preparations, motivating forces, and execution techniques to optimize the affect of green rooftops in diminishing energy usage, improving city livability, and meeting carbon lower targets.

8. Conclusion and Future Research

This look at demonstrates that inexperienced roofs provide a possible and economically feasible solution for boosting city sustainability in China. The proposed business model integrates environmental blessings with economic incentives, leveraging an e-trade platform to streamline adoption. Green roofs provide huge electricity savings, reduce urban warmness island results, enhance air first-rate, and decorate stormwater management. The price-benefit evaluation highlights a promising go back on funding (ROI) and relatively brief payback intervals, specially for commercial and business homes. However, challenges such as excessive preliminary charges, protection necessities, and regulatory inconsistencies remain barriers to large-scale implementation. By addressing those obstacles thru monetary incentives, coverage aid, and public-personal partnerships, green roofs can turn out to be a mainstream urban infrastructure issue. The large adoption of green roofs aligns with China's dual dreams of economic boom and environmental sustainability. By lowering power intake, these installations decrease operational costs for building proprietors even as simultaneously mitigating climate alternate thru carbon sequestration. Additionally, they make a contribution to progressed urban biodiversity, decreased noise pollutants, and elevated property values, fostering healthier and extra resilient cities. Green roofs additionally function a crucial device in climate adaptation techniques, lowering city flooding and reducing reliance on artificial cooling systems. Implementing supportive guidelines, subsidies, and regulatory frameworks can in addition boost up adoption, reinforcing the transition towards greener

urban landscapes. Future studies ought to explore long-time period performance reviews of inexperienced roofs throughout various climatic areas in China, assessing variations in efficiency primarily based on vicinity, constructing type, and plant life selection. Pilot projects in principal urban centers may want to provide actual-international validation of the enterprise version, refining monetary projections and operational strategies. Further research need to also take a look at technological improvements, including sensor-based tracking and AI-pushed protection answers, to optimize overall performance and reduce protection costs. Additionally, research on public perception and stakeholder engagement strategies can help identify effective conversation techniques to promote adoption. Lastly, comparative studies between China and other global leaders in inexperienced infrastructure, consisting of Singapore and Copenhagen, could provide treasured insights into exceptional practices and coverage innovations. By addressing these regions, destiny studies can contribute to a greater comprehensive expertise of how inexperienced roofs may be effectively included into China's urban sustainability projects, making sure their lengthy-term viability and maximizing their monetary and environmental impact.

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