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Comparison of green building research progress in China and south Korea: Trends and development 2001–2023

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Abstract: The development of green buildings is influenced by factors such as time, politics, society, economy, climate, and culture. China and South Korea share certain similarities in these areas and, since 2020, have both committed to specific carbon peaking and carbon neutrality goals. This study aims to compare green building research trends in China and South Korea, identifying key developments, differences, and shared challenges. It provides a brief overview of research progress in both countries since 2001 through a content review, followed by a comparative analysis across timelines and sub-dimensions, including technical, economic, legal, and systemic aspects. Additionally, a questionnaire survey was conducted with industry professionals in both countries to supplement the findings. The results indicate that while research directions are broadly similar, there are significant differences in specific topics and focus areas. Variations in timing and policy implementation also contribute to divergences in green building development. Moreover, both countries face common challenges that require further research and discussion. This analysis may offer valuable insights and references not only for China and South Korea but also for other developing nations.

Keywords: *Comparative study, Green building; Professional questionnaire survey, Sustainable development, Systemic analysis.*

1. Introduction

As global warming intensifies, humanity has become increasingly aware of the dangers posed by greenhouse gases like CO_2, which are produced through fossil fuel consumption, even as conventional energy prices continue to rise [1]. Carbon and other pollutants emitted by cities significantly contribute to global warming and climate change, which the United Nations has identified as a major cause of natural disasters [2]. Meanwhile, in 2021, the construction industry accounted for over 34% of global energy demand, a 5% increase from 2020 and 2% higher than pre-COVID-19 levels in 2019 United Nations Environment Programme [3] indicating a consistent upward trend. According to a United Nations report, by 2050, 66% of the global population is expected to live in cities, underscoring the importance of reducing energy consumption in the construction industry to lower overall greenhouse gas emissions [4]. As a result, the development of green buildings has become imperative.

The evolution of green buildings is shaped by various domestic factors, including temporal, political, social, economic, cultural, and climatic elements [5]. China and South Korea share similar cultural traits influenced by Confucianism, which emphasizes harmony and balance [6]. Climatically, both countries experience distinct seasonal changes, with cold winters and hot summers. Additionally, both nations have undergone rapid industrialization and urbanization, resulting in challenges such as urban pollution and high energy consumption [7]. These issues have fostered awareness of green buildings and motivated efforts to address them.

Since 2000, both countries have actively responded to global economic changes, including financial crises, achieving significant economic development while implementing policy reforms to sustain

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growth [8, 9]. In 2020, the United Nations officially recognized South Korea as a developed country [10]. Both nations also share strong similarities in their energy characteristics, having become major energy consumers in Asia while remaining heavily reliant on energy imports. As of 2021, China and South Korea ranked as first and fourth largest energy consumers in Asia, and first and tenth globally, respectively [11]. China has been the world's largest oil importer since 2013, whereas South Korea, with limited domestic resources, depends more heavily on external energy sources [12, 13].

Furthermore, these countries rank first and eighth globally in carbon emissions [14]. Construction-related carbon emissions account for 51.3% and 42% of the total emissions in China and South Korea, respectively [15, 16]. In response, both countries have actively committed to reducing carbon emissions. In 2020, China announced its goal to achieve peak CO_2 emissions by 2030 and carbon neutrality by 2060 [1]. South Korea implemented the "Carbon Neutrality and Green Growth Act" in 2022, setting a target to reduce greenhouse gas emissions by 40% from 2018 levels by 2030 and achieve carbon neutrality by 2050 [17]. Therefore, the development of green buildings is essential in both countries.

However, relying solely on central governments or legal regulations to reduce greenhouse gas emissions may not be sufficient [16, 18]. To address the emissions issue effectively, it must be tackled at its source [19]. As the construction industry is one of the major sources of global carbon emissions, its green transformation is particularly important. Therefore, to promote the development of green buildings, a comparative analysis and summary of research in both countries is essential. Such an analysis not only facilitates mutual learning between China and South Korea but also offers valuable insights and practical references for other nations, particularly developing countries. Furthermore, it provides a foundation for decision-making, helping policymakers evaluate and refine existing policies.

2. Research Scope and Methods

This study builds upon previous research findings on green buildings in both China and South Korea. Prior investigations thoroughly explored the field of green building research in these two countries. This study conducted a comparative analysis based on these previous insights. Additionally, it carried out a survey with professionals from relevant industries in both countries, involving 25 participants from China and 19 from South Korea.

Although the beginning of green building research in both countries dates back to the late 1990s, significant developments have occurred in both economies since the beginning of the 21st century. Economic progress has strongly supported the rise of green buildings, creating favorable conditions for the development of this field from both subjective and objective perspectives. Hence, this study focused on the period from 2001 to 2023 for analysis.

3. Theoretical Background

Owing to the diversity in geographical conditions and climate characteristics, as well as economic levels and policy orientations, there is no uniformity among nations in establishing standards for green buildings. However, the common goal is to steer development towards greater sustainability and environmental friendliness. Conserving resources, protecting the environment, creating comfortable and healthy living spaces, and promoting harmony between people, buildings, and the natural environment have become universally accepted core principles [20].

The green building definition presented by the United States Environmental Protection Agency is widely recognized internationally. This definition emphasizes resource conservation and environmental responsibility throughout the life cycle of a building [20]. This comprehensive definition reflects a deep understanding of green building sustainability.

Due to its unique geographical characteristics, Germany focuses on heating to reduce energy consumption. It also prioritizes indoor air quality, positioning energy conservation and good air quality as core objectives of green building development [21, 22]. Additionally, Germany implemented the

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Energy Conservation Act in 2013, requiring all new public buildings to meet near-zero energy consumption standards starting in 2019 [23].

China and South Korea began research in this field relatively late, dating back to around 2000. During this period, both countries recognized the urgent need for energy conservation and pollution mitigation. This recognition subsequently drove the development and popularity of green buildings in both nations.

In 2006, China published the 'Green Building Evaluation Standards,' which emphasize the maximization of energy conservation and emission reduction, protection of the ecological environment, and provision of efficient and healthy living spaces for residents throughout the entire lifecycle of the building [24, 25]. The 'Green Building Action Plan' launched in 2020 placed greater emphasis on the operational management of green buildings and called for legislation to promote the responsibilities of all stakeholders [11]. China has highlighted the significant role played by the green economy in driving the development of green buildings [26, 27].

South Korea's green building definition encompasses the entire lifecycle from construction to demolition, with a focus on mitigating environmental damage (Green Building, Knowledge Encyclopedia). This definition reflects South Korea's commitment to creating a comfortable living environment, conserving resources, and protecting the natural environment, aiming to achieve broader development goals through these measures [25].

Table 1.
Main areas and Sub-dimensions of green building research on China and South Korea.

	China	**South Korea**
Main areas	economy, Incentive policy, building renovation, evaluation index systems, energy-saving technology, building energy-saving systems, building energy-saving management systems	improvement and development of evaluation index system, economic-related, energy-saving technology, relevant regulation, building renovation, building energy-saving management system, building energy-saving system, popularization and development of green buildings
Sub-dimensions	technical, economic, systemic, policy	technical, economic, legal, systemic, popularization and development of green buildings

4. Review of Previous Study

Detailed reviews of green building research development trends in China from 2001 to 2022 Ren and Kim [28] and South Korea from 2001 to 2023 (Ren and Kim, 2024) were conducted. It is shown in Table 1 that the literature on China and South Korea covers seven and eight main areas, respectively, which are further divided into four and five sub-dimensions.

4.1. China Context

From 2001 to 2005, China's research primarily focused on introducing green building concepts and certifications from abroad, with government support for energy-saving technologies. The introduction of energy-efficient design criteria for public buildings in 2005 marked a significant milestone. In the following period, from 2006 to 2010, the focus shifted to energy-saving technologies and economic incentives, including subsidies and tax benefits. Research conducted between 2011 and 2015 emphasized energy-saving technologies, evaluation systems, and economic feasibility. The publication of the new Green Building Evaluation Criteria in 2014 further underscored the progress during this period. From 2016 to 2020, China intensified its focus on green, low-carbon development, placing priority on green finance. Since 2020, research has expanded to include Artificial Intelligence (AI) applications in building energy design and user perceptions in eco-friendly buildings.

Technical research initially focused on building materials, energy utilization, and energy-saving technologies, with increasing attention to systemic energy-saving measures and renewable energy sources. Since 2016, the emphasis shifted to energy-saving design and software. Economic research

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explored energy-saving, market demand, financing, and the circular economy, with increased focus on green finance after 2016. Policy research supported green building development through economic incentives, with a growing focus in recent years on policies promoting new technologies such as AI and big data. Systemic research initially concentrated on evaluation systems, but later shifted to energy efficiency and the renovation of existing buildings.

4.2. South Korea Context

From 2001 to 2005, South Korea's research introduced green building concepts and energy-saving technologies, with a focus on enhancing indoor environments and establishing green building material standards. In 2008, the 'Low-Carbon Green Growth' vision was declared, leading to the enactment of the 'Low-Carbon Green Growth Act' in 2010. Between 2011 and 2015, the focus was on improving evaluation systems and promoting the adoption of green buildings. The introduction of the Green Standard for Energy and Environmental Design (G-SEED) certification system in 2013 represented a significant development. From 2016 to 2020, the Green New Deal emphasized sustainable economic growth, with research focusing on energy-saving technologies and mandatory certification. After 2020, the implementation of the 'Carbon Neutrality and Green Growth Basic Act' in 2022 set ambitious greenhouse gas reduction targets, with research prioritizing improving evaluation standards and building renovations.

Technical research initially focused on eco-friendly materials, then gradually transitioned to digitalization and intelligent building design and management. Economic research examined market demand, life cycle costs, and the economic impact of certification systems, with a growing focus on these systems after 2016. Research on the popularization and development of green buildings emphasized education and application, although related studies became less frequent after 2016. Systemic research initially had few studies but gained attention on management and evaluation systems after 2010, utilizing technologies like Building Information Modeling (BIM). Legal research began in 2010, sporadically concentrating on comprehensive revisions of laws and policies related to green buildings.

5. Comparison of Green Building Research Between China and South Korea

5.1. Comparison by Time Periods

5.1.1. 2001-2005

The research and development of green buildings in China and South Korea began in the 21st century, supported by their respective governments. During this period, the Chinese government emphasized the importance of green buildings in the development of the construction industry through its five-year national development plan. The plan set policy goals and guidelines while increasing financial support for the research and promotion of energy-saving technologies. Despite these efforts, the concept of green buildings was not yet widely promoted in China. The Korean government launched a green building certification system in 2002, initially for new residential buildings, and expanded it to school buildings in 2005, highlighting its emphasis on building energy efficiency and green building importance.

During this period, China was still in the preliminary stages of green buildings, lacking a specific certification system and primarily exploring green building concepts, principles, and evaluation indicators. By 2005, China had promulgated the 'Jiang [29]' which primarily focused on improving the energy efficiency of public buildings and reducing energy consumption. Meanwhile, South Korea's green building certification system was more comprehensive. Korean research began to prioritize energy-saving technologies, including high-efficiency insulation materials, windows, and lighting systems. There was also an emphasis on improving indoor environments, as well as refining evaluation standards and databases for green building materials. Overall, from 2001 to 2005, China lagged behind South Korea in green building research, though the concept and theory of green buildings began to gain attention.

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5.1.2. 2006-2010

In 2006, the Chinese government released green building evaluation standards, marking a significant step forward in the scientific and systematic evaluation of green buildings. During this period, South Korea incorporated low-carbon green growth into its national strategy, shifting its growth model to prioritize quality, new energy, renewable energy, and green technology, and implemented 'low-carbon, green growth' regulations in 2010. Green building evaluation standards were updated to emphasize the balance between environmental management and economic growth.

Judging from their research during this period, both China and South Korea focused on energy-saving technologies, with China emphasizing incentive policies and South Korea concentrating on economic factors and the popularization of green buildings. There were both similarities and differences in their approaches to energy-saving technologies. The similarities included the verification of geothermal system design performance and the enhancement of wall insulation performance. The difference was that China's focus included the conservation and utilization of water resources, energy-saving lighting, and tools like building energy monitoring systems and energy-saving assessment software. In contrast, South Korea's research concentrated on developing green building materials and passive cooling technology, with an emphasis on educating building users. Additionally, reducing indoor noise levels to enhance living comfort was also considered. From this perspective, South Korea not only led in the development of green building materials but was also ahead of China in promoting green building concepts, particularly in user education.

In economics-related research, China emphasized marketing green buildings and increasing public awareness of energy conservation through economic incentives and the rational distribution of energy conservation costs. Research in South Korea found that green building ratings had little impact on apartment prices and suggested promoting market development through tax incentives and financial support. This highlighted that both countries faced challenges of low market recognition and weak public awareness when promoting private green buildings, underlining the need for government intervention through economic incentives. Additionally, China required policy measures for active government intervention, demonstrating that the development and promotion of green buildings relied heavily on strong government incentives.

In terms of the popularization of green buildings, South Korea was at the forefront, proposing specialized recommendations for different building types and green building strategies to address social issues like aging. Additionally, it recommended establishing a comprehensive linkage system, including professional education, certification system operations, and public social education. In terms of design, both countries emphasized the integration of architecture with the natural environment and the harmonious coexistence of humans and nature. They prioritized environmental protection, approached green building design from the perspective of user needs and space planning, and began exploring architectural renovations.

Overall, during this period, both countries had distinct focuses in green building research and practice. China strengthened its systematic evaluation of green buildings, while South Korea focused on advancing green building development. These efforts laid the foundation for future advancements.

5.1.3. 2011-2015

Similar to the previous period when South Korea incorporated low-carbon green growth into its national strategy, China strengthened its research and application of green buildings as a key strategy for creating a 'resource-saving and environment-friendly society.' In 2013, it promulgated the 'Energy Saving and Reduction Policy.' Subsequently, China's first comprehensive green building standards, 'Zhang, et al. [30]' and 'Lim, et al. [31]' were promulgated. Meanwhile, South Korea, which had made early achievements in 2002, enhanced its green building certification system and officially renamed it G-SEED. The certification scope was expanded to include various types of buildings: apartments, office buildings, complex facilities, sales points, accommodation facilities, and schools. By integrating several previous relevant regulations, a comprehensive green building law was implemented in 2013.

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In comparison, China's research primarily focused on the evaluation system, energy-saving technologies, economic feasibility, and incentive policies. South Korea's research primarily emphasized improving the evaluation index system, followed by the popularization and development of green buildings, energy-saving technologies, and economic factors.

In terms of the evaluation system, both countries focused on improving their respective green building evaluation systems. However, China's approach involved studying green building standards from the United States, Europe, and other countries to inspire improvements in its own evaluation system. South Korea, by contrast, relied on its decade-long experience with its evaluation system to address certification process issues and propose improvements. These included revising renewable energy assessment standards, creating separate evaluations for existing and newly certified buildings, and formulating detailed plans like G-SEED roadmaps and public participation strategies.

In terms of technology, both countries focused on developing and applying environmentally friendly building materials, with an emphasis on renewable energy sources such as solar power and geothermal systems. Both nations also developed high-performance thermal insulation materials. Regarding the use of intelligent technologies, such as BIM, China favored integrating smart technologies to reduce systemic energy consumption during the operational phase of buildings. South Korea, on the other hand, utilized intelligent technologies to conduct environmental performance analyses during the design and construction phases of green buildings.

In terms of economics, both countries utilized concepts such as Life Cycle Cost (LCC) theory for the economic analysis of green buildings. However, the application of LCC in China remained limited, with a lack of systematic research. During the same period, both countries proposed research on the systematic application of Life Cycle Assessment (LCA) theory to green buildings. Additionally, South Korea proposed measures to manage green buildings effectively, ensuring certified buildings do not negatively impact the environment.

In terms of relevant regulations, both countries introduced economic incentives, including property tax exemptions, loan interest subsidies, and green building subsidies. However, China primarily focused on incentives and policies at different levels, ranging from central to local governments and from property owners to public building managers. In contrast, South Korea not only proposed economic stimulus measures but also recommended modifying relevant laws and improving land-use systems.

South Korea continued to lead in the popularization and development of green buildings. The design and construction of green buildings were tailored to meet national conditions, including addressing the needs of an aging society. Additionally, there was an emphasis on providing education to users and considering the opinions of various stakeholders, including architects, users, and certification consultants. This approach reflects the humanistic care and foresight embedded in Korean society.

In summary, during this period, China concentrated on developing green building standards and evaluation systems, alongside advancing technological innovation and policy incentives to construct a resource-saving and environment-friendly society. South Korea led the way in enhancing its green building certification system, popularizing green buildings, and refining related regulations. These efforts demonstrated the humanistic care and foresight of Korean society. Both countries also achieved significant breakthroughs in applying smart technologies.

5.1.4. 2016-2020

China conducted an in-depth reflection and planned to achieve its goals of peaking carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060. For example, insufficient research investment, technological lag, and the immaturity of the green building market highlighted the need for 'green, low-carbon, circular development' as the core development concept. China also emphasized the necessity of green development in urban and rural areas and planned to establish a complete green development mechanism and policy system by 2025. To implement these concepts concretely, China released the third edition of the 'Green Building Evaluation Standards' in 2019. The standards included specific requirements for green building design, introduced new concepts such as building intelligence,

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and promoted the construction of ecological cities. However, the coronavirus disease (COVID-19) pandemic in late 2019 delayed or suspended green building projects, leading the Chinese government to respond by increasing financial subsidies, preferential policies, and technical support.

Simultaneously, the South Korean government took proactive measures. It formulated the '2030 Greenhouse Gas Emissions Reduction Roadmap' and the 'Basic Plan to Address Climate Change' in 2016, followed by the '2050 Long-term Low-Carbon Development Strategy' in 2017. In addition, it implemented a zero-energy building certification system, which was expected to gradually make zero-energy buildings mandatory by 2020. In terms of green building certification standards, South Korea added green renovation certification standards through the G-SEED certification system and introduced separate standards for residential and non-residential buildings. In response to the COVID-19 pandemic, South Korea introduced a green policy focusing on sustainable economic reform and using green transformation for economic recovery.

During this period, China's research focused on energy-saving technology and economic aspects, while South Korea concentrated on improving and developing an evaluation index system, as well as energy-saving management systems and technologies for green buildings. South Korea proposed improvements to the evaluation system and explored future development directions, whereas China conducted less research in this area during this period. In terms of energy-saving technology, both countries emphasized the use of renewable energy and research on green building materials, with a particular focus on recycled and natural materials. China concentrated more on overall energy-saving measures and architectural design. Regarding energy-saving management systems, South Korea emphasized managing green building operations to minimize environmental impact. In contrast, China had limited research in this area during this period. In terms of the economy, China began to emphasize green finance, focusing on investment decisions and financing methods for green-building projects. South Korea, on the other hand, concentrated on improving economic efficiency by reducing costs and carbon emissions. This difference highlighted the distinct economic strategies of the two countries: China promoted green building projects through financial markets to drive environmental protection and sustainable growth, whereas South Korea leveraged technological innovation and efficiency improvements to enhance economic competitiveness and reduce energy consumption and carbon emissions.

Overall, both countries made significant progress during this period, strengthening their commitment to sustainable development and expanding national-level efforts to advance green building initiatives beyond earlier efforts in vigor and scope.

5.1.5. Post 2020

China released the updated 'Green Building Energy-Saving Evaluation Standards' in 2021, introducing more stringent requirements for energy consumption, indoor environments, building materials, and water use. It also established standards for ecological adaptability and resource recycling. Additionally, China clarified the conditions and procedures for the use of green building labels. Meanwhile, South Korea advanced its Green New Deal, transitioning toward a sustainable low-carbon economic growth model. In 2022, South Korea implemented the 'Carbon Neutral Green Growth Basic Law,' which set targets to reduce greenhouse gas emissions to 40% below 2018 levels by 2030 and achieve carbon neutrality by 2050. South Korea also strengthened its green building certification standards, requiring that all new or renovated public school buildings larger than 3,000 square meters meet the green building certification criteria.

The Chinese government announced plans to establish 100 national-level green building demonstration zones by 2030, while South Korea integrated green building development into its smart city practices and research, adopting a more comprehensive and forward-looking approach. These strategies reflect the differing development priorities and paths of the two countries.

Since 2020, China has primarily focused on energy-saving technologies and building energy management systems, while South Korea has prioritized building renovations and enhancing its evaluation

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index system. South Korea has suggested strengthening indoor air quality and acoustic environment evaluation standards, as well as developing separate standards for specific building types to address special circumstances, such as aging populations and single-person households, reflecting its social humanistic care and foresight. China has proposed studying architecture from a user perception perspective and supplementing its indoor acoustic environment evaluation standards, a proposal similar to South Korea's during the period 2006–2010. However, there remains a relative lack of research on specific domestic social issues in China. Additionally, South Korea recommends using BIM technology to assist in green building assessments to ensure the reliability of the results.

Chinese researchers have noted that green buildings often overemphasize design and construction, while neglecting operation and maintenance in building energy-saving management systems. They recommend clarifying owners' and users' responsibilities for operation and maintenance, and strengthening incentives and legal supervision. South Korea had already proposed managing green building operations relatively earlier. However, both countries face a common challenge: a lack of specific management methods and systematic research, highlighting the need for further exploration of green building management systems.

Regarding energy-saving technology, China is exploring the application of artificial intelligence in building energy-saving designs, focusing on intelligent control and management of green buildings through building intelligence, the Internet, and sensor technologies. South Korea, in the realm of building renovation, has proposed incorporating actual energy-saving rates into retrofitting existing buildings, simplifying certification processes, and encouraging private participation through economic measures such as tax incentives and construction cost subsidies.

Meanwhile, China has increased its focus on ecological adaptability and resource recycling by implementing stricter building energy-saving standards and promoting green demonstration zones. Similarly, South Korea has reinforced its commitment to low-carbon sustainable development through key laws and continuous improvements to its green building certification standards. Despite differing research focuses, both countries have shown a strong commitment to advancing green buildings.

5.2. Comparison by Sub-Dimensions

5.2.1. Technical

When examining research on the technical sub-dimension in China and South Korea, certain similarities emerge in their focus and development trajectories. In China, research encompasses energy utilization, building structure, building materials, and system energy-saving technologies, while in South Korea, it focuses on energy utilization, building materials, and digitalization.

As shown in Figure 1, China began focusing on technological research in 2006. Before 2016, the focus was primarily on developing energy-saving technologies, including water and renewable resource utilization, energy-efficient building design, and energy-saving materials. Since 2016, the emphasis has shifted toward the digitization and intelligence of system energy-saving technologies and building energy-efficient designs. This shift includes developing models and systems that use advanced technologies and software to enhance performance efficiency through intelligent technology at the user level.

South Korea began research in related fields after 2000. Before 2011, the focus was primarily on developing green building materials and utilizing renewable resources. After 2011, research gradually shifted toward the digitalization and intelligence of green building design and construction, while continuing the development of green building materials. Smart technology has been applied to analyze environmental performance across all stages of green building design and construction.

Overall, although China entered the intelligence phase about five years later than South Korea, both countries initially focused their research on renewable resource utilization and green material development. Progress in these technical sub-dimensions has been relatively slow, likely due to the greater complexity and longer research cycles inherent to this field.

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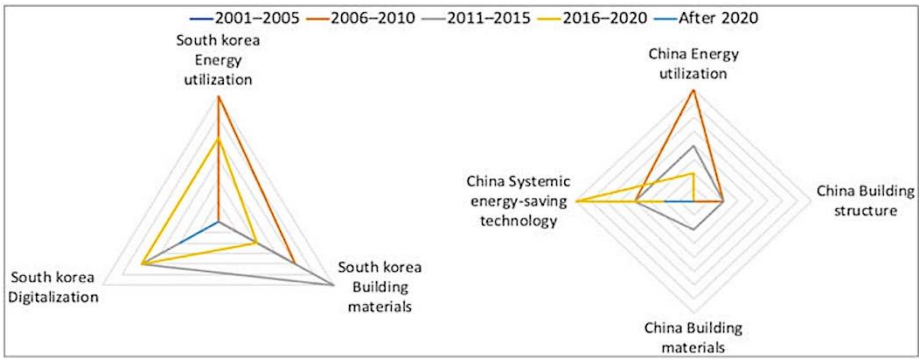

Figure 1.
Comparison of technical sub-dimensions.

5.2.2. Economic

The economic sub-dimension of green building research in China encompasses energy savings, market demand, financing, investment, the circular economy, and economic theory, while South Korea focuses on life-cycle costs, market demand, and certification systems, as shown in Figure 2. From a timeline perspective, China's research was relatively active between 2006 and 2020, driven largely by the government's strong promotion of green financing. The decline in related research after 2020 can be partly attributed to the COVID-19 pandemic. South Korea's research on the economic sub-dimension began in 2006, focusing initially on life-cycle costs and market demand. After 2016, the focus shifted toward the economic impact of the green building certification system, particularly its influence on the construction industry's economic aspects.

The two countries take markedly different approaches to economic research. China emphasizes promoting green building development through financial aspects, including market demand, financing, investment, and consumer perspectives. In contrast, South Korea primarily examines the economic aspects of the buildings themselves. Although both countries study market demand, South Korea's research prioritizes the perspectives of upper-level decision-makers rather than ordinary consumers.

Overall, both countries have demonstrated unique advantages and challenges in their green building economic research models. The Chinese model excels at accelerating green building practices and rapidly expanding the market. However, it is vulnerable to risks such as market fluctuations; for instance, an economic recession could reduce market demand, prioritizing short-term economic gains over long-term sustainability and environmental benefits. In contrast, the Korean model emphasizes long-term economic sustainability and high-quality standards by focusing on life-cycle costs and the economic impacts of certification systems. Nevertheless, this approach may hinder broader market promotion and consumer adoption, potentially slowing technological advancement and innovation in the field.

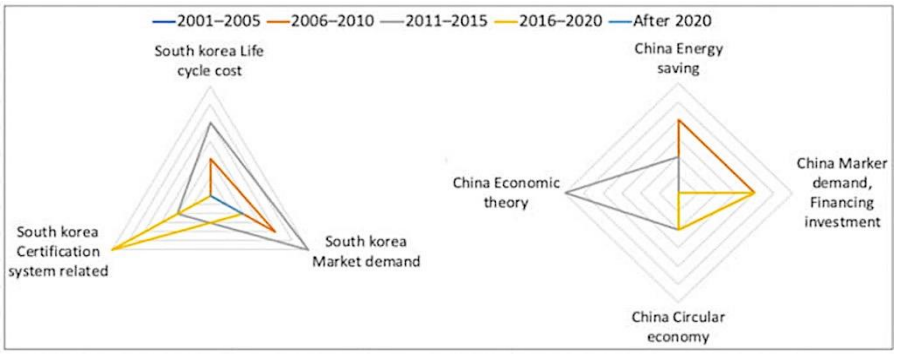

Figure 2.
Comparison of economic sub-dimensions.

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5.2.3. Legal (Policy)

China and South Korea also demonstrated different approaches in the legal (policy) sub-dimension, as shown in Figure 3. The development and research of green buildings heavily depend on legal and policy support. In China, economic and policy incentives, particularly financial incentives, play a crucial role in driving green building development. This reliance explains China's preference for financial instruments, such as financing and investments. Relevant research has been ongoing since 2006 but has declined since 2018, likely due to the slowdown in economic growth and the impact of the COVID-19 pandemic.

Research in this field in South Korea began in 2010 and has primarily focused on comprehensively revising existing green-building-related laws and policies. One reason for the relatively limited number of studies in this area is that South Korea integrated several relevant regulations in 2013, established a comprehensive green building law, and implemented the 'Carbon Neutral Green Growth Basic Law' in 2022. Additionally, necessary changes have been managed without revising laws by updating and improving the green building assessment system.

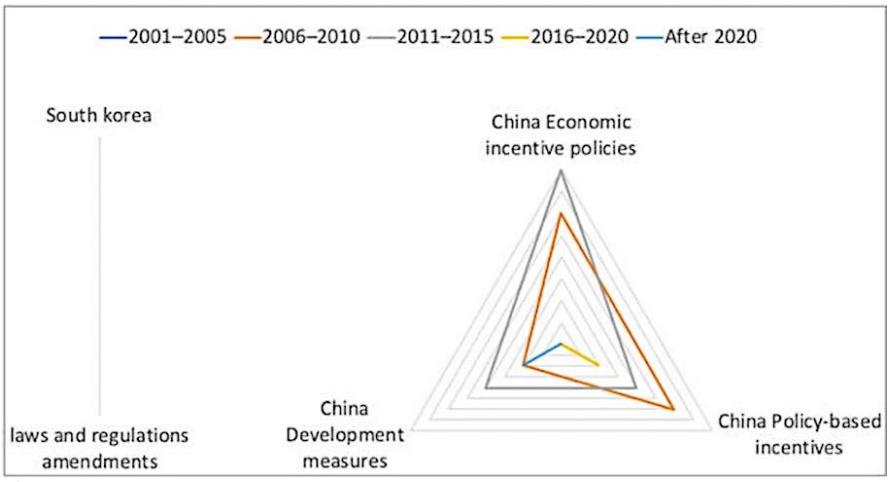

Figure 3.
Comparison of legal (policy) sub-dimensions.

5.2.4. Systemic

For the systemic sub-dimension, both countries emphasize evaluation, energy-saving, and management systems, as shown in Figure 4. In China, research on establishing an evaluation system was relatively limited before 2006. However, studies on evaluation and energy-saving systems have steadily increased since then. Notably, after the Chinese government released a new version of building energy efficiency evaluation standards in 2014, research shifted toward standards for renovating existing buildings. Similarly, such research in South Korea was also limited before 2006. With the implementation of the Green Building Certification System in 2002, the focus was on management systems, particularly the development of a classification system for green building materials. After 2006, nearly a decade of experience with the certification system revealed various problems and deficiencies, prompting academia to conduct in-depth research to further advance green building development.

In terms of energy-saving systems, research in China began in 2006, focusing on building energy-saving models, green city systems, residential energy-saving support systems, and energy-saving design software. By contrast, South Korea initially concentrated on heating and cooling systems and the systemic design of green buildings. After 2010, the focus shifted to adopting new technologies, such as BIM, to minimize energy loss and monitor buildings' energy usage and carbon emissions.

Research on management systems in China remains limited. While the concept of building lifespan has been discussed, it has not yet been explored in depth. This indicates that the Chinese government prioritizes technological development and the green economy over management, which may have limited

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researchers' interest in this area. In contrast, before 2010, most research in South Korea focused on the classification system for green building materials. After 2010, the emphasis shifted to underscoring the importance of green building management through detailed data and theoretical approaches.

Overall, both countries focus on evaluation and energy-saving systems in their research on systemic sub-dimensions, but notable differences exist. Since China released its building energy efficiency evaluation standards in 2014, research on evaluation systems has been limited. The lack of continuous updates and improvements may hinder the system's optimization and adaptability to new challenges. In contrast, South Korea, which implemented its green building certification system as early as 2002, has consistently prioritized research on evaluation systems, aiming to refine and supplement them continuously. This ongoing effort has facilitated the development of green buildings and the adoption of new technologies. Regarding energy-saving systems, South Korea places greater emphasis on integrating new technologies and optimizing system performance, supporting more efficient and sustainable building designs. Additionally, its focus on the early development and application of energy-saving models and technologies has provided a robust technical foundation for the green building sector.

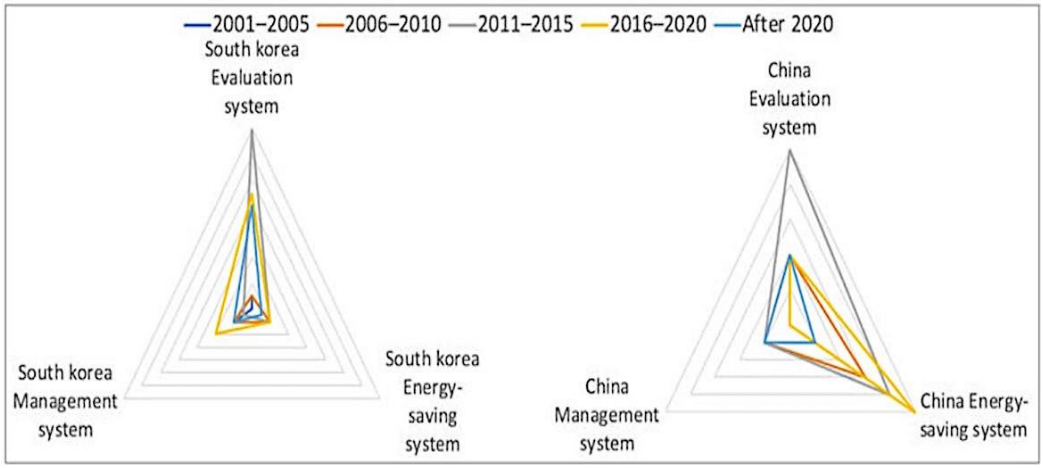

Figure 4.
Comparison of systemic sub-dimensions.

6. Survey and Analysis of Expert Opinions

A questionnaire survey was designed to validate research findings, identify shortcomings, and highlight potential areas for improvement. It also aimed to gather insights from professionals in China and South Korea regarding green buildings and their perspectives on industry and academic exchange. The survey comprised four sections: basic information, evaluation of research findings, perceptions of differences in green building research between the two countries, and opinions on industry and academic exchange. The survey targeted professionals with extensive experience in green building research and practice to ensure informed feedback. Questionnaires were distributed and collected via email and online platforms to gather genuine feedback from respondents. In total, 44 questionnaires were retrieved, including 25 from China and 19 from South Korea.

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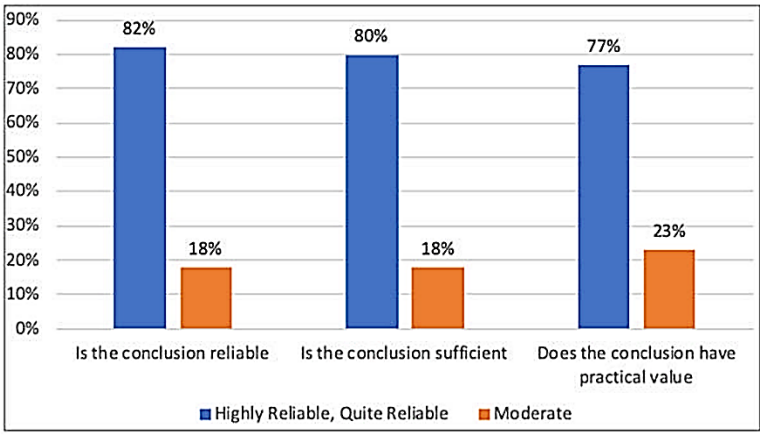

Figure 5.
Evaluation of research findings.

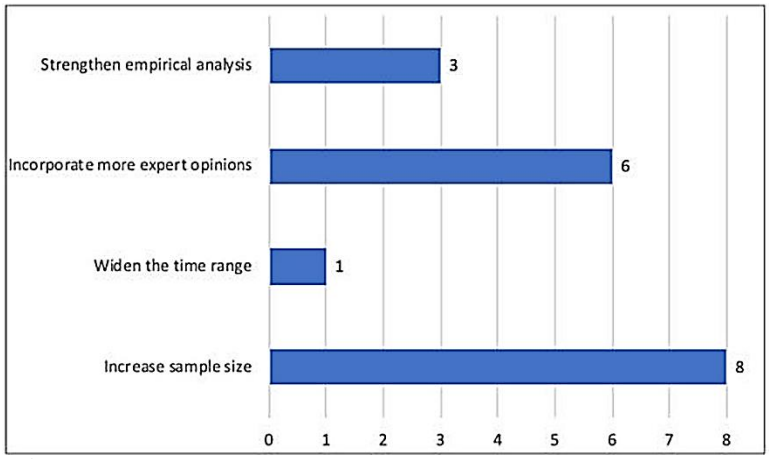

Figure 6.
Suggestions for improvement.

Based on the discussion of differences in green building research between China and South Korea, respondents identified significant disparities in areas such as policy support (78%), research focus (61%), technological development (52%), and industrial application (45%), as shown in Figure 7. Most Chinese respondents believe that China's research is more advanced in green finance, strengthening market mechanisms, and applying green building practices in rural areas. In contrast, most Korean respondents indicated that South Korea excels in smart building systems, environmentally friendly interiors, and human-centered design. According to the survey, 70% of respondents attributed these differences to cultural, humanistic, and national contextual factors, 66% to policies and regulations, 64% to social needs and market mechanisms, and 52% to economic development levels. The specific data are illustrated in Figure 8.

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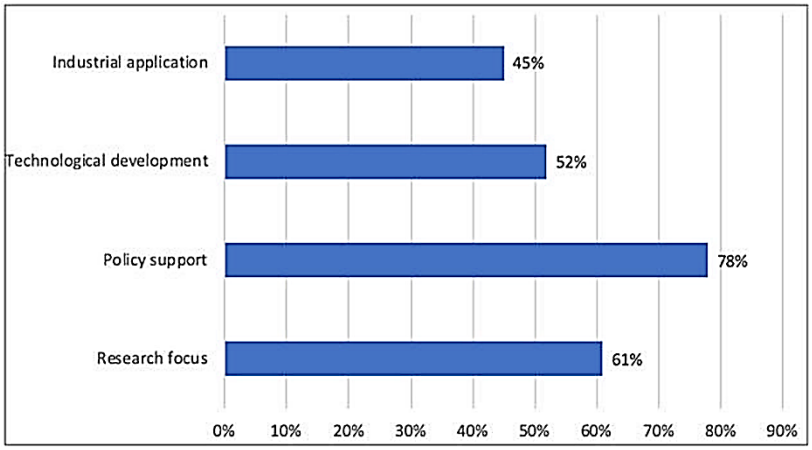

Figure 7.
Differences in green building research.

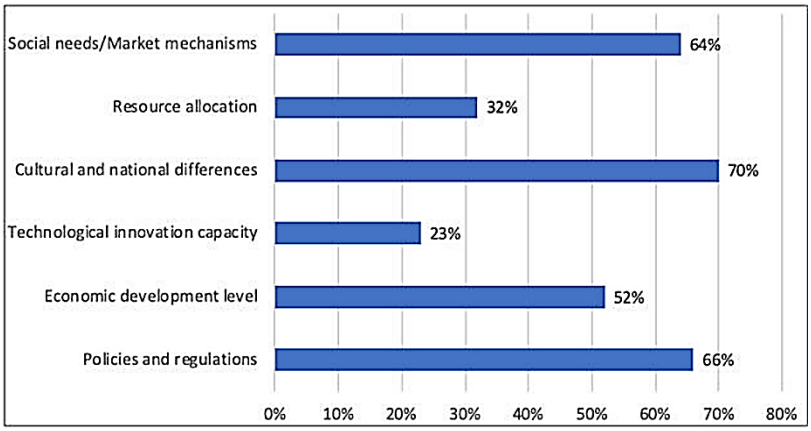

Figure 8.
Reasons for the differences in green building.

Finally, regarding industry and academic exchange, over 80% of respondents agreed that both countries should focus on innovation and the practical application of energy-saving technologies, along with public engagement. Chinese respondents emphasized the need to consider differing policy environments and economic conditions, while Korean respondents highlighted the importance of enhancing collaboration on researching and standardizing energy management systems.

7. Summary and Conclusions

China and South Korea face similar environmental and social challenges. Since 2020, both countries have intensified efforts toward carbon peaking and carbon neutrality, highlighting the strategic importance of green building development. This study provides a comprehensive comparative analysis of green building development in the two countries, examining different periods and key areas such as technology, economics, policy, and management. It also offers practical references and guidance for other countries, promoting progress in green building across multiple dimensions, including environmental sustainability, technological innovation, economic benefits, and social responsibility.

Since the beginning of the 21st century, both China and South Korea have made significant progress in green building development and research, largely driven by strong government support. Comparative analysis reveals that while China initially lagged five to ten years behind South Korea in certain areas, both countries share similar research focuses but employ distinct approaches. From 2000

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to 2005, South Korea achieved steady advancements in green building policies and technologies, while China rapidly began gaining research momentum. Between 2006 and 2010, their development paths diverged: China concentrated on systematic evaluation, while South Korea advanced green building promotion. From 2011 to 2015, both countries made substantial progress: China established standards and incentives to foster innovation, while South Korea enhanced certification systems and promoted human-centered green building regulations. Between 2016 and 2020, both countries introduced robust national policies to foster green building development aligned with carbon reduction goals. More recently, China has emphasized ecological adaptability and resource recycling, while South Korea has focused on low-carbon building models and refining its certification standards.

In technical research, both countries initially focused on renewable resources and green materials, gradually transitioning to intelligent systems at different rates. Economically, China prioritized market-driven financing and investment strategies, whereas South Korea emphasized the economic impact of construction costs and certification systems, with a focus on long-term sustainability. In policy formulation, China concentrated on incentive mechanisms, while South Korea adopted a comprehensive legislative approach to green building. Regarding systemic evaluation, South Korea has consistently maintained its focus, while China's emphasis on this aspect has declined since 2014, reflecting a divergence in research priorities. Additionally, South Korea has extended its research to the popularization of green buildings, proposing strategies tailored to specific national conditions and building types, whereas China's research in this area remains in its early stages.

Both countries face shared challenges. For example, due to high technological demands, lengthy development timelines, and uncertain returns, progress in green building materials has been slow, and therefore requires further policy and financial support from both governments and investors. Additionally, imposing stringent deadlines and performance-based criteria for promotion may inadvertently stifle researchers' motivation. In the realm of management systems, effective scientific management remains underexplored, especially in China, where technical considerations often overshadow management needs. Both countries would benefit from more specific and systematic management approaches and stricter standards to ensure consistency throughout the building lifecycle. User-centered management strategies, supported by real-time energy monitoring technology, are essential. In China, in particular, increased government support could stimulate research and innovation in this area.

With carbon reduction a top priority for both governments, concepts like green cities and smart cities are gaining momentum alongside advances in artificial intelligence and big data. A 'people-oriented' approach highlights the need to balance technical and environmental standards with human well-being in green building development. Tackling these challenges requires collaboration across society, including government, business, and academia, with a focus on cross-disciplinary efforts to foster innovation and advance green building initiatives.

From China's perspective, South Korea's strategies and experiences in green building R&D, particularly in enhancing and developing evaluation index systems, offer valuable insights. China should thoroughly analyze the limitations and practical challenges of its green building evaluation system and carefully explore future pathways to address social issues like an aging population and the rise in single-person households. Establishing tailored standards for different demographic groups and building types is crucial. Moreover, it is necessary to develop standards for green building materials, databases, and outdoor environmental assessment benchmarks. Enforcing these standards through green building-related laws will ensure legal support and compliance. Additionally, creating an integrated system that links professional education, certification operations, and public awareness campaigns will lay the groundwork for sustainable progress. Economically, China should shift its focus from the financial aspects of green buildings to long-term economic sustainability and quality standards, fostering more comprehensive and in-depth development in this field.

From South Korea's perspective, although the country leads in green building research, there are still valuable lessons to be learned from China's development strategies. While South Korea places

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emphasis on green materials research, a systematic exploration of energy-saving technologies could be beneficial. As green buildings ultimately serve end-users, the economic perspectives of consumers should not be overlooked. China's approach of leveraging financing, investment, and other economic tools to promote green building development has accelerated practical applications and expanded the green building market. Korean researchers and policymakers should explore effective economic tools to further advance green building development. South Korea's extensive experience in the popularization, education, and legislation of green buildings provides a solid foundation for strengthening and expanding these initiatives.

This study not only fosters mutual learning between China and South Korea but also offers valuable experience and references for other countries, particularly developing nations. By providing a comprehensive comparative analysis between developed and developing countries, it enables other nations to understand the key elements of green building development at various stages. This understanding helps them avoid the challenges and mistakes faced by early adopters, save time and capital costs, and formulate more targeted green building strategies tailored to their specific national contexts.

While the study focuses on keywords related to green, eco-friendly, and energy-efficient buildings, some studies from various periods may have been overlooked. Additionally, there is a time lag in the publication of papers, with China's research period being one year shorter than South Korea's. Future research could refine the methodology and include a more in-depth content review. Comparative analyses of global leaders in green building, such as the United States and the United Kingdom, could also be beneficial. Examining their historical trajectories, key development stages, and driving forces would help support the localization of advanced technologies, concepts, and methods, thereby proposing multifaceted pathways to improve and advance green buildings more effectively.

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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