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SUSTAINABLE DEVELOPMENT OF INNOVATION HUBS IN THE INDIAN GREEN BUILDING SECTOR

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Abstract. This research aims to analyse the factors influencing the sustainable development of innovation hubs in the Indian green building sector. The research focuses on the significance of innovation hubs in enhancing sustainability in the Indian green building sector. These hubs decrement costs, improve market value, attract huge investments and generate job opportunities. Innovation hubs promote reducing waste, effectively using resources and mitigating carbon emissions. Incorporating advanced green technologies through innovation hubs helps to develop more eco-friendly architectural solutions. The authors utilized quantitative methodologies to gather and analyse the acquired data. Primary data is collected through a digital survey, and secondary data is acquired by retrieving information from articles and journals of academic databases. Snowball sampling was used by the authors, and 150 individuals participated in the survey. The obtained data is analysed using the Chi-square test and Spearman correlation to identify the strength of the relationship between identified variables and innovation hubs in the green building sector in India. The factors are government policies and regulations (0.709), technological advancements (0.648), skilled workforce (0.517), market demand (0.619), public-private partnerships (0.527), and supply chain efficiency (0.501). A model is developed to enhance the sustainable innovation hubs in green buildings in India.

Keywords; *Chi-squared test, green-building, innovation hubs, Spearman correlation, sustainable development.*

INTRODUCTION

The increasing popularity of green building technologies provides various benefits to the environment, economy and society. These technologies prioritize the full utilization of resources and energy to enhance environmental conditions, improve health, increase productivity and low both operations and maintenance expenses (Meena et al., 2022). The construction sector approximately consumes 40 % of energy and contributes to approximately 33 % of greenhouse gas emissions. Developing a new evaluation system through green building technologies helps to reduce negative environmental effects. There are various definitions and rating standards that are given to green buildings, which showcase the conservation of energy, raw materials, land as well as water and enhance environmental quality. Due to the present pollution crisis, the number of green building models is increasing in South Asian countries like India (Lu et al., 2020). The green building construction is impeded by multiple obstructions like government regulations, high construction costs and lack of professional expertise. The other main barrier is to encourage and provide guidance to individuals to promote sustainability. To tackle these concerns, stakeholders of the green building construction industry should work together to adopt ecologically friendly building practices (Sharma, 2018).

The various key criteria in green building certification are a selection of eco-friendly sites, water efficiency, conserving energy and atmosphere, raw materials and resources, as well as the quality of the indoor environment. Choosing sustainable sites is important for reducing greenhouse emissions and fluctuations in climate through utilizing sustainable transport, habitat restoration and water management (Beniwal & Kumar, 2024). Water efficiency is achieved through rainwater harvesting techniques which help to recycle water and conserve 50 % of water. Energy and atmosphere are conserved through using energy-efficient lighting and appliances, leading to reduce approximately 30 % in energy consumption. Materials and resources are recycled through the 3R (reduce, reuse and recycle) principle to reduce waste generation. Indoor environmental quality is enhanced through proper ventilation systems, sustainable materials and zero-VOC products (Manna & Banerjee, 2019).

Innovation hubs have a vital role in the green building sector by encouraging collaboration and easing the adoption of innovative technologies like additive manufacturing. Integrating ecologically friendly processes and materials into construction helps to decrease project costs and delays. Carbon footprint is reduced through integration along with enhancing operational efficiency. Innovation hubs interconnect energy-efficient designs and eco-friendly raw materials to decrease ecological impact, improving resource efficiency. Thus, sustainability is promoted in the building sector (Vijayakumar & Davidova, 2024). Innovation hubs, therefore, play a vital role in the green building sector of India by adopting innovative, cutting-edge technologies as well as eco-friendly building techniques. The opportunities for entrepreneurs, academic institutions, corporate businesses and regulatory bodies to collaborate are increased through these types of hubs, along with developing new sustainable construction solutions (Agrawal et al., 2024).

The authors mainly focus in this research on the utilization of innovation hubs in the green building sector to implement sustainable practices and technologies. This presents a comprehensive understanding of the benefits of innovation hubs in enhancing energy efficiency, handling resources as well as customer engagement in order to promote sustainability. Additionally, this research also emphasizes the enhancement of the green building sector of India through sustainable innovation hubs.

The main aim of this research is to evaluate the factors affecting the sustainable development of innovation hubs in the green building sector of India. It is rare in previous studies regarding factors that positively influence the sustainable development of innovation hubs in the green construction sector within India.

Hence, an amalgamation of these factors became necessary for the thorough study regarding the collaboration of innovation hubs with the green construction sector of India. The factors affecting the sustainable development of innovation hubs in the Indian green building sector have been obtained from the literature review. These factors are used to enhance the performance of green buildings in India through proper usage. A recommendation plan has been suggested for the performance increase according to their relevance.

1. INTEGRATION OF THE GREEN BUILDING SECTOR AND INNOVATION HUBS IN SUSTAINABLE DEVELOPMENT

The expansion of innovation hubs in India’s green construction sector is influenced by many significant variables. In order for green technologies to flourish and advance, the government enacts legislation that promotes their development and provides sufficient funding to support their growth (Darko & Chan, 2017). The factors affecting the sustainable development of innovation hubs in the Indian green building sector are given in Fig. 1.

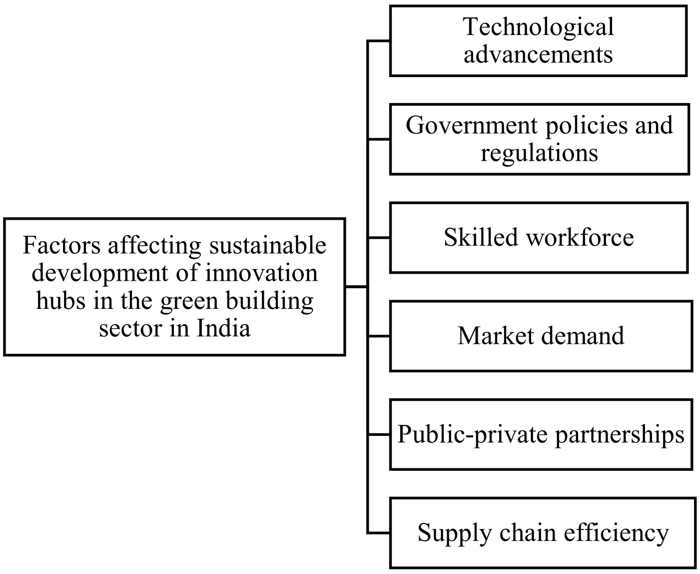

Fig. 1. Factors affecting sustainable development by innovation hubs and the green building sector (created by authors).

The factors elucidated by the authors in the following section are advancements in technology, government policies and regulations, skilled workforce, market demand, public-private partnerships, and supply chain efficiency.

1.1. Influence of Technological Advancements

Technological advancements revolutionize the green building sector of India as it helps to build long-lasting eco-friendly structures. These advancements increment workers’ productivity and safeguard their health along with optimizing the utilization of resources, water as well as energy. This reduces the generation of waste, pollution levels and other related ecological damage. Developing innovation hubs helps to increase collaboration of advanced technologies in the green building sector of India, promoting sustainability (Mishra et al., 2013).

Advancements in green technologies decrease the consumption of energy and enhance thermal comfort in the building industry of India. These developed technologies depend on sustainable energy sources like solar power and heating, ventilation and air conditioning (HVAC) systems. Evaluating climatic conditions and humidity in building sites using technologies helps architecture and contractors to build as per green building principles. Knowledge sharing and collaboration in innovation hubs accelerate the process (Gibberd, 2019).

Various technologies like building information modelling (BIM) and the Internet of Things (IoT) help to maintain sustainability in construction. BIM facilitates the process of planning, constructing and operating green buildings. Through BIM, a digitalized model of the building, which is integrated with sustainability principles, is developed. BIM also helps stakeholders and contractors to identify problems and enhance building performance which helps to decrease the ecological footprint (Ahuja et al., 2020; Mohanta & Das, 2022). The Internet of Things helps in acquiring data, real-time monitoring and managing smart building systems. IoT devices are usually integrated with sensors and smart meters to acquire diverse data like energy utilization, humidity and temperature. Furthermore, it enhances the collaboration of renewable energy sources, which reduces the environmental impact (Bathre & Das, 2020; Prathyusha & Ajitha, 2021).

H1. Sustainable development through the integration of innovation hubs and green buildings in India is influenced by technological advancements.

1.2. Influence of Government Policies and Regulations

Government policies and regulations are actively encouraging the development of green building structures. The government introduces various policies like carbon pricing and charging costs for greenhouse gas emissions, which helps to align with the objectives of the Paris Agreement. This reduces carbon emission rate and promotes sustainable development (Debrah et al., 2022).

The Indian government encourages the construction of green buildings by providing a certification by the Indian Green Building Council (IGBC) and faster environmental clearance. The government provides various other incentives for construction projects rated by IGBC. People always perceived green buildings as costly construction, and this hinders many Indian people from promoting sustainable building. Reducing prices through government programs makes the green building concept affordable for people, and a greater number of projects are developed (Singh & Gupta, 2021). IGBC collaborate with both central and state governments of India to encourage green practices in India. For instance, the Punjab government in India provides an extra floor area ratio (FAR) and relaxations on building evaluation costs for IGBC gold-rated projects. Likewise, Rajasthan, Jharkhand, Himachal Pradesh, Haryana and West Bengal also provide the same incentives. The Maharashtra government made it mandatory that new government buildings must follow IGBC guidelines. Small Industries Development Bank of

India collaborate with the Indian government to provide financial assistance for green construction projects. This encourages sustainable development (Manna & Banerjee, 2019). The second hypothesis developed is as follows.

H2. Sustainable development through the integration of innovation hubs and green buildings in India is influenced by government policies and regulations.

1.3. Influence of Skilled Workforce

For the successful completion of green building construction in India, highly skilled workers are required. They should have expertise in energy-efficient technologies, complex construction processes and eco-friendly materials. The workforce that is not adequately trained fails to meet the green building standards (Mistri et al., 2019). Innovative green technologies are crucial for guaranteeing the continuous growth as well as the progress of the green building industry. Adopting intelligent building systems, using superior materials, and harnessing renewable energy sources are among the innovative approaches that enhance energy efficiency and reduce the ecological damage due to buildings. This requires high professional skills for workers (Huang et al., 2022).

A skilled workforce enables the adoption of complex construction techniques and technologies to work with durable, sustainable materials and accelerates green construction. Project managers need to face various challenges related to technology and complexities if workers are not adequately skilled. This causes project delays and additional financial burdens. The training programs provided through innovation hubs help workers to utilize green technologies properly and contribute to efficient, sustainable development in the Indian green building sector (Kumar & Tawalare, 2021). The third hypothesis statement is given below.

H3. Sustainable development through the integration of innovation hubs and green buildings in India is influenced by skilled workers.

1.4. Influence of Market Demand

Market demand is a crucial factor in promoting green building construction in India. there is an increase in popularity towards green construction among corporate as well as residential sectors in India, which increases the demand. As per the records, the demand for green building could reach up to 8 billion in coming years. Various studies revealed that when buyers, developers, and regulatory bodies collaborate and promote sustainability leads to an increment in demand for green buildings in the Indian construction market (Grover, 2015).

The increment in population growth increases the demand for housing in India. Understanding economic benefits and awareness about ecological impact, a greater number of people in India are ready to invest in green buildings that help to enhance their living conditions. GBC further motivates people to adopt green building construction. As a result, innovation hubs are developed with the objective of sustainable construction practices to help stakeholders and buyers in promoting sustainable development through green building construction (Manoj, 2013). The demand for properties increases as people are more aware of the advantages of green building. Marketers need to fulfil the needs and expectations of customers regarding both quality and price. Marketing campaigns organized by green building associations and the government further escalate the market demand. Therefore, market demand serves a vital role in ensuring the sustainable progress of green buildings through innovation hubs in India (Jat & Mane, 2018).

H4. Sustainable development through the integration of innovation hubs and green buildings in India is influenced by market demand.

1.5. Influence of Public-Private Partnerships

Public-private partnerships (PPPs) are essential in ensuring the sustainable development of the green building industry of India through integration with innovation hubs. By integrating the professional expertise and resource sharing of both public and private sectors, PPPs help in sustainable infrastructure development. These strategic partnerships decrement risk and develop innovative solutions that accomplish high-quality standards and reduction in price. PPP introduces "green entrepreneurship" and attract large investments into eco-friendly construction in India (Patil & Laishram, 2016).

As innovation hubs showcase quality and encourage collaboration, PPPs help to attain high-quality standards with affordable costs. PPPs help to develop a strong network by including buyers, stakeholders and the government, which increases the adoption of green buildings and improves the living conditions of people (Vassileva, 2022). Through public-private partnerships, various challenges in sustainable infrastructure development are tackled. The PPPs provide a platform for both the government and private sector to indulge in discussions by enhancing benefits and addressing shortcomings. This partnership forum through innovation hubs helps to propose practical solutions and enhance sustainable development in the green building sector (Rahangdale, 2020).

H5. Sustainable development through the integration of innovation hubs and green buildings in India is influenced by public-private partnerships.

1.6. Influence of Supply Chain Efficiency

An efficient supply chain helps to promote sustainable development in green building construction in India through innovation hubs. Implementing green warehousing and transit practices decreases both ecological impact and costs. Better green logistics operations help to reduce carbon emissions significantly. The enhanced site logistics and decrement in traffic congestion by adopting green logistics improve brand reputation. The reverse logistics, as well as efficient building waste management, ensures sustainability (Koul et al., 2023). Sustainable goals are accomplished through efficient supply chain management, which helps to source, utilize and allocate green raw materials for construction. Green supply chain management promotes a circular economy. The relation between innovation hubs and green buildings in sustainable development is enhanced through the effective supply chain adopted in green building construction in India (Mathiyazhagan et al., 2018; Mojumder & Singh, 2021).

H6. Sustainable development through the integration of innovation hubs and green buildings in India is influenced by supply chain efficiency.

2. METHODS AND PROCEDURES

The authors utilized standard and organized procedures to collect data required for research and analysis.

2.1. Data Measures

The authors opted for the quantitative approach as the methodological approach. The quantitative methodology helps to identify the patterns and interconnection, and relationships using numerical data. Additionally, it helps authors to analyse a large sample size with high reliability. This methodological approach is extremely effective in testing the hypothesis statements (Mohajan, 2020).

The authors used two different types of data acquisition methods in this research. Primary and secondary data collection are the two different methods. Secondary data is gathered by authors by performing a detailed literature review analysis. The authors retrieved various journals and articles from academic databases such as Google Scholar and Scopus database. To get the latest knowledge regarding green building construction and innovation hubs in ensuring sustainable development, the authors considered the majority of articles dated from 2014 to 2024, which is within the 10-year limit. Based on acquired secondary data, the authors developed six research hypothesis statements, which are presented in Fig. 2.

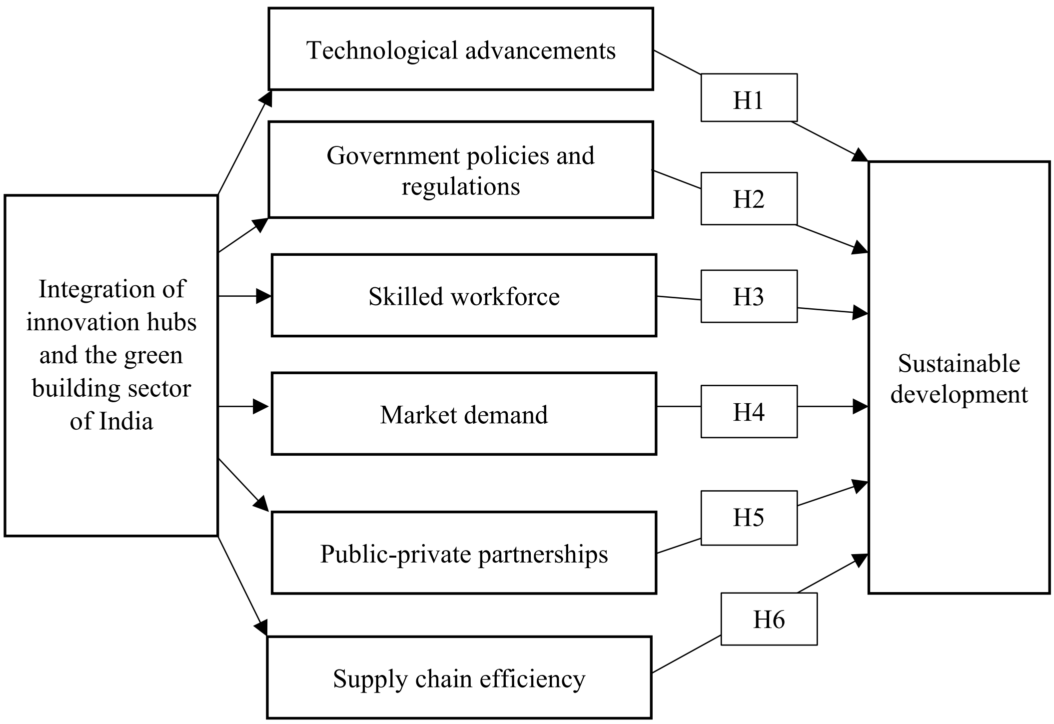

Fig. 2. Development of research hypothesis statements (created by authors).

A digital survey created using the web platform Google Forms helps authors acquire required primary data. The authors sent invitation links to 200 individuals and collected a total of 150 sample sizes. Ethical guidelines are followed by authors during the survey conducted. The survey questionnaire did not contain any questions that reveal the personal information regarding participants that may identify them. A total of 15 questions were created by authors in the English language for wider understandability.

Before conducting the actual survey, the authors conducted a pilot study to evaluate the whole survey questionnaire. 30 individuals participated who were either employees of the construction sector or academic researchers. They participated in the survey independently and provided various suggestions to improve the survey questionnaire. The authors made the appropriate corrections in the survey questionnaire according to the feedback of the review group. Additionally, the authors conducted Cronbach's alpha test to assess the reliability of survey items in the pilot study. The value obtained is 0.812, which is deciphered as good consistency. The final survey questionnaire was then sent to various individuals using online platforms.

2.2. Research Sample and Data Analysis Techniques

Snowball sampling is the sampling method utilized by the authors to collect large sample sizes within a short time. In this sampling method, the authors selected a group of participants, and these participants chose the next set of respondents. This chain of referral continued till the authors received the required sample size (Kennedy-Shaffer et al., 2021). The survey respondents are sustainability experts, architects, civil engineers, employees of the construction sector, and academic researchers. The respondents are from various parts of India, as the research is about the Indian construction market scenario. 150 individuals from the various professions mentioned above participated in the online survey.

The acquired data is analyzed by using the Chi-squared test and Spearman correlation analysis. The Chi-squared test is utilized by the authors to find out the relationship between identified variables and the sustainable development of innovation hubs within green buildings in India. If the Chi-square value is less than the critical value, no association is found out (Aslam & Smarandache, 2023). Whereas the Spearman correlation test helps to measure the degree of relationship strength between the identified variables and sustainable development of innovation hubs in the Indian green building construction (Zheng et al., 2022).

3. RESULTS AND ANALYSIS

The dependent variable is the sustainable development of innovation hubs and the green building sector in India. The independent variables are technological advancements, government policies and regulations, skilled workforce, market demand, public-private partnerships and supply chain efficiency. To evaluate the consistency of survey items of 150 samples (items referred to as each question about identified factors), Cronbach's alpha is conducted. The test revealed a value of 0.875 which is indicated as high consistency.

Firstly, the authors performed the Chi-square test and evaluated the significance value. If the variable failed in the Chi-squared test, the authors did not proceed to Spearman correlation analysis. The respective variable is eliminated, and the hypothesis statement is rejected. According to Selala et al. (2019), the rho value of Spearman correlation has the following interpretations. A value between 0.21 and 0.40, indicates a weak correlation, and from 0.41 to 0.60, showcases a moderate correlation. Variables having values from 0.61 to 0.80 show a strong correlation, and values above 0.81 to 1 have very strong correlation.

3.1. Analysis of Technological Advancements

The first hypothesis statement developed by the authors is related to the influence of technological advancements. Table 1 presents the respective results of Chi-squared test.

Table 1. Chi-squared Test Result on Technological Advancements (SPSS 29 software)

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-square	7.203	8	0.001
Likelihood ratio	7.784	8	0.002
Linear-by-linear association	0.236	1	0.001
N of valid cases	150		

It is evident from Table 1 that the Chi-square value obtained is 0.001, which is less than 0.05. This shows that a relationship exists between technological advancements and sustainable development of innovation hubs in green building in India. To identify the degree of the relationship, the authors performed the Spearman correlation test. Table 2 presents the corresponding results.

Table 2. Spearman Correlation Test Result on Technological Advancements (SPSS 29 software)

<table>
<tr><th colspan="3"></th><th>Sustainable development of innovation hubs in the green building sector</th><th>Technological advancements</th></tr>
<tr><td rowspan="6">Spearman’s rho</td><td rowspan="3">Sustainable development of innovation hubs in the green building sector</td><td>Correlation coefficient</td><td>1.000</td><td>0.648</td></tr>
<tr><td>Sig. (2-tailed)</td><td>-</td><td>0.001</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
<tr><td rowspan="3">Technological advancements</td><td>Correlation coefficient</td><td>0.648</td><td>1.000</td></tr>
<tr><td>Sig. (2-tailed)</td><td>0.001</td><td>-</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
</table>

Table 2 shows that the significance value obtained is 0.001, which meets the criteria of a value that must be less than 0.005. The correlation coefficient is 0.648, which lies between 0.61 and 0.80 deciphered as there is a strong association between the independent variable and dependent variable. Since the correlation is a positive value, technological advancements strongly enhance the sustainable development of innovation hubs and green buildings in India.

3.2. Analysis of government Policies and Regulations

The second hypothesis statement is related to the government policies and regulations factor. Table 2 presents the findings of the Chi-squared test conducted on the factor "government policies and regulations".

Table 2. Chi-squared Test Result on Government Policies and Regulations (SPSS 29 software)

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson chi-square	18.054	7	0.000
Likelihood ratio	14.569	7	0.001
Linear-by-linear association	0.000	1	0.001
N of valid cases	150		

Table 2 shows that the significance value obtained after performing the chi-squared test is 0.000, which is less than 0.05. Hence, government policies and regulations are related to the sustainable development of innovation hubs in the green building sector of India. The subsequent step is the Spearman correlation analysis, and Table 3 provides the respective results.

Table 3. Spearman Correlation Test Result on Government Policies and Regulations (SPSS 29 software)

<table>
<tr><th colspan="3"></th><th>Sustainable development of innovation hubs in the green building sector</th><th>Government policies and regulations</th></tr>
<tr><td rowspan="6">Spearman's rho</td><td rowspan="3">Sustainable development of innovation hubs in the green building sector</td><td>Correlation coefficient</td><td>1.000</td><td>0.709</td></tr>
<tr><td>Sig. (2-tailed)</td><td>-</td><td>0.001</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
<tr><td rowspan="3">Government policies and regulations</td><td>Correlation coefficient</td><td>0.709</td><td>1.000</td></tr>
<tr><td>Sig. (2-tailed)</td><td>0.001</td><td>-</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
</table>

Table 3 infers that after performing Spearman correlation, the significance value obtained is 0.001, which is less than 0.05. This matches with the results of the Chi-squared test. The correlation coefficient value obtained is 0.709, which is deciphered as a strong correlation exists between government policies and regulations and the sustainable development of innovation hubs within the green building sector in India.

3.3. Analysis of Skilled Workforce

The authors developed a third hypothesis statement based on the factor "skilled workforce". To determine the existence of the relation between the identified variable and the dependent variable, the authors conducted a Chi-squared test using SPSS 29 software. Table 4 provides the corresponding results of this test.

Table 4. Chi-squared Test Result on Skilled Workforce (SPSS 29 software)

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson chi-square	12.324	9	0.001
Likelihood ratio	11.025	9	0.003
Linear-by-linear association	0.001	1	0.001
N of valid cases	150		

Referencing Table 4, the significance value obtained for the skilled workforce is 0.001. This met the criteria. Therefore, the authors identified a relation between the skilled workforce and the sustainable development of innovation hubs within the green building industry in India. Table 5 presents the result of Spearman correlation analysis test.

Table 5. Spearman Correlation Test Result on the Skilled Workforce (SPSS 29 software)

			Sustainable development of innovation hubs in the green building sector	**Skilled workforce**
Spearman's rho	Sustainable development of innovation hubs in the green building sector	Correlation coefficient	1.000	0.517
		Sig. (2-tailed)	-	0.000
		N	150	150
	Skilled workforce	Correlation coefficient	0.517	1.000
		Sig. (2-tailed)	0.000	-
		N	150	150

Table 5 reveals that the skilled workforce has a significance value of 0.000 less than 0.05, which aligns with the chi-squared test results. The correlation coefficient value obtained is 0.517, which lies between 0.41 and 0.60, indicating moderate correlation. This revealed that the sustainable development of innovation hubs in the green building sector of India is moderately enhanced by a skilled workforce.

3.4. Analysis of Market Demand

The fourth hypothesis statement developed by the authors is based on the factor "market demand". The authors conducted a Chi-squared test on market demand to find out the existence of the relationship. Table 6 presents the result of the respective Chi-squared test.

Table 6. Chi-squared Test Result on Market Demand (SPSS 29 software)

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson chi-square	10.239	12	0.000
Likelihood ratio	13.456	12	0.004
Linear-by-linear association	0.000	1	0.001
N of valid cases	150		

Table 6 infers that the factor "market demand" has a significance value of 0.000 (less than 0.05), which deciphers that market demand is connected to the sustainable development of innovation hubs in the green building industry of India. Table 7 presents the Spearman correlation analysis test result on market demand.

Table 7. Spearman Correlation Test Result on Market Demand (SPSS 29 software)

<table>
<tr><th colspan="3"></th><th>Sustainable development of innovation hubs in the green building sector</th><th>Market demand</th></tr>
<tr><td rowspan="6">Spearman's rho</td><td rowspan="3">Sustainable development of innovation hubs in the green building sector</td><td>Correlation coefficient</td><td>1.000</td><td>0.619</td></tr>
<tr><td>Sig. (2-tailed)</td><td>-</td><td>0.002</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
<tr><td rowspan="3">Market demand</td><td>Correlation coefficient</td><td>0.619</td><td>1.000</td></tr>
<tr><td>Sig. (2-tailed)</td><td>0.002</td><td>-</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
</table>

Based on the test results of Spearman correlation analysis, the significance value and correlation coefficient value obtained are 0.002 and 0.619, respectively.

This showcases that market demand strongly enhances the sustainable development of innovation hubs within the green building industry in India.

3.5. Analysis of Public-Private Partnerships

The fifth hypothesis developed by the authors is sustainable development through the integration of innovation hubs and the green buildings sector in India is influenced by public-private partnerships. To identify the relationship between the identified independent variable, "public-private partnerships", and the dependent variable, a Chi-squared test is conducted. Table 8 presents the corresponding result of this test.

Table 8. Chi-squared Test Result of Public-Private Partnerships (SPSS 29 software)

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson chi-square	14.152	11	0.001
Likelihood ratio	12.537	11	0.003
Linear-by-linear association	0.001	1	0.001
N of valid cases	150		

The significance value obtained for public-private partnerships revealed in Table 8 is 0.001, which completed the Chi-squared test criteria. Therefore, the authors proceeded to the Spearman correlation test. Table 9 presents the result of the above-mentioned test.

Table 9. Spearman Correlation Test Result on Public-Private Partnerships (SPSS 29 software)

<table>
<tr><th colspan="3"></th><th>Sustainable development of innovation hubs in the green building sector</th><th>Public-private partnerships</th></tr>
<tr><td rowspan="6">Spearman's rho</td><td rowspan="3">Sustainable development of innovation hubs in the green building sector</td><td>Correlation coefficient</td><td>1.000</td><td>0.527</td></tr>
<tr><td>Sig. (2-tailed)</td><td>-</td><td>0.002</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
<tr><td rowspan="3">Public-private partnerships</td><td>Correlation coefficient</td><td>0.527</td><td>1.000</td></tr>
<tr><td>Sig. (2-tailed)</td><td>0.002</td><td>-</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
</table>

The significance value and correlation coefficient value after the Spearman correlation test on public-private partnerships are 0.002 and 0.527, respectively.

From the Spearman correlation analysis criteria, the obtained values indicate that public-private partnerships moderately improve the sustainable development of innovation hubs in the Indian green building industry.

3.6. Analysis of Supply Chain Efficiency

The last hypothesis statement developed by the authors is that supply chain efficiency influences sustainable development through the integration of innovation hubs and the green building sector in India. Table 10 presents the values obtained after Chi-squared test performed on supply chain efficiency.

The result presented in Table 10 shows that the significance value of supply chain efficiency is 0.001. This value deciphered that supply chain efficiency is related to the ustainable development of innovation hubs within the green building industry of India.

Table 10. Chi-squared Test Result on Supply Chain Efficiency (SPSS 29 software)

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson chi-square	14.152	11	0.001
Likelihood ratio	12.537	11	0.003
Linear-by-linear association	0.001	1	0.001
N of valid cases	150		

As supply chain efficiency met the Chi-square test criteria, the authors proceeded to the next step of data analysis, the Spearman correlation test. This helps to evaluate the strength of the relationship. Table 11 presents the test results on the factor of supply chain efficiency.

Table 11. Spearman Correlation Test Result on Supply Chain Efficiency (SPSS 29 software)

<table>
<tr><th colspan="3"></th><th>Sustainable development of innovation hubs in the green building sector</th><th>Supply chain efficiency</th></tr>
<tr><td rowspan="6">Spearman's rho</td><td rowspan="3">Sustainable development of innovation hubs in the green building sector</td><td>Correlation coefficient</td><td>1.000</td><td>0.501</td></tr>
<tr><td>Sig. (2-tailed)</td><td>-</td><td>0.002</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
<tr><td rowspan="3">Supply chain efficiency</td><td>Correlation coefficient</td><td>0.501</td><td>1.000</td></tr>
<tr><td>Sig. (2-tailed)</td><td>0.002</td><td>-</td></tr>
<tr><td>N</td><td>150</td><td>150</td></tr>
</table>

Table 11 shows that the significance value and correlation coefficient of supply chain efficiency are 0.002 and 0.501, respectively. This indicates that supply chain efficiency moderately enhances the sustainable development of innovation hubs in the green building sector of India.

3.7. Discussion

According to the studies of Beniwal and Kumar (2024), Meena et al. (2022), and Sharma (2018), the green building technologies are revolutionizing the whole Indian construction industry to shift to sustainability as well as environmental responsibility. This type of technology encompasses innovative energy management frameworks, solar panels, energy-efficient lighting systems, and intelligent HVAC systems, which help to reduce the consumption of energy. Eco-friendly materials like low VOC paints, fly ash bricks, and recycled steel are used by green building constructors. The certifications and ratings given by IGBC help buyers receive various incentives to integrate this technology in constructing both residential and commercial projects.

The studies conducted by Agrawal et al. (2024) and Vijayakumar and Davidova (2024) align with the findings of the authors of this research, as innovation hubs integrated in the Indian construction sector help to develop and implement new innovative technologies, which in turn increases efficiency, sustainability as well as productivity. These hubs also provide a favourable environment where stakeholders, researchers, and professionals can collaborate and work together to ensure sustainability, smart construction techniques and other energy-efficient designs.

As per the aim of this research, the authors identified six major factors that affect the sustainable development of innovation hubs within eco-friendly construction practices in India. The identified six factors are technological advancements, government policies and regulations, skilled workforce, market demand, public-private partnerships and supply chain efficiency.

The studies by Ahuja et al. (2020), Gibberd (2020), Mishra et al. (2013), and Prathyusha and Ajitha (2021) put forward that technological advancements like the Internet of Things (IoT) and Building Information Modelling (BIM) significantly influence the sustainability of innovation hubs in the green building industry in India. The research Chi-squared test reveals that there exists a relation between technological advancements and the sustainable development of innovation hubs integrated into green buildings in India, as the significance value obtained is 0.001. Based on the Spearman correlation analysis, the strength of the relationship between the identified factor and sustainable development is 0.648. The technological advancements help to develop eco-friendly technologies to enhance energy efficiency and productivity. This helps to design the building digitally and utilize renewable sources of energy like solar, wind and hydro in the building, ensuring sustainability. Therefore, the first hypothesis statement is validated.

According to Debrah et al. (2022) and Singh and Gupta (2021), government policies and regulations significantly influence adopting sustainability initiatives in the Indian green building through innovation hubs. These findings are in line with the authors' research results. The significance value obtained for this factor after the Chi-squared test is 0.000, and the correlation coefficient was 0.709, which interprets that government policies and regulations have a strong positive connection with implementing sustainable practices within green building through innovation hubs. The government policies and reforms encourage more companies and buyers to invest in green building technologies and construct sustainable buildings. Various schemes and rules reduce the financial burden and spread awareness about the significance of green building. This shifts the decision of customers to sustainable buildings. Therefore, the second hypothesis statement is accepted.

The research Chi-squared test established an interconnection existing between the skilled workforce and the development of sustainability in innovation hubs within the green building construction of India as its significance value is 0.001. Additionally, the Spearman correlation analysis conducted in this research also found the degree of relation that exists, which was 0.517. These data analysis results point out that the skilled workforce moderately influences the sustainable development of innovation hubs implemented in the green building sector in India. Skilled workers have high professional expertise in utilizing green technologies and designing construction using technologies promoting sustainability. They also help to fully utilize the potential of these innovative technologies. The studies conducted by Huang et al. (2022), Kumar and Tawalare (2021), and Mistri et al., (2019), also shared similar viewpoints to those of the authors of this research. Hence, the third hypothesis statement is proved.

From the research Chi-squared test and Spearman correlation test, the authors found a relation between market demand and sustainable development of innovation hubs in eco-friendly building practices in India, as the significance value and correlation coefficient values are 0.000 and 0.619, respectively. The correlation coefficient value indicates that the strength of the relation is strongly positive. With the awareness level regarding ecological issues and other schemes provided by the government, a greater number of individuals shifted to green buildings. They are ready to pay a premium amount for these facilities to enhance their living conditions. This escalates market demand, and a greater number of people are shifted to this transformation which ensures sustainability. The studies of Grover (2015), Jat and Mane (2018), and Manoj (2013) also state that market demand strongly enhances the sustainable development of innovation hubs, which are integrated into the green building sector in India. Thereby, the fourth hypothesis statement is accepted.

Based on the research chi-square test, the factor of public-private partnerships has a crucial role in ensuring the sustainable development of innovation hubs in the green building industry of India with a significant value of 0.001. Furthermore, the correlation coefficient value obtained after conducting the Spearman correlation analysis is 0.527, which indicates that public-private partnerships moderately increase the sustainable development of green buildings integrated with innovation hubs in India. Public-private partnerships encourage collaboration, resource and knowledge sharing, which helps stakeholders and buyers to understand green buildings and their future benefits. This also attracts huge investment into this sector, and sustainable development goals are achieved. These findings align with the studies of Patil and Laishram (2016) and Vassileva (2022). Therefore, the fifth hypothesis statement is accepted.

Furthermore, Koul et al. (2023) and Mathiyazhagan et al. (2018) also noted the influence of supply chain efficiency in sustainable development in their studies. The chi-square test and Spearman correlation analysis performed in this research about supply chain efficiency validate the studies by obtaining a significance value of 0.001 as well as a correlation coefficient value of 0.501, indicating that supply chain efficiency moderately influences the integration of innovation hubs and green building sector in India for sustainable development. An efficient supply chain helps in mitigating carbon emissions and increases the utilization of eco-friendly resources. This helps to align the construction works with sustainable development goals. Therefore, the sixth hypothesis statement is accepted. In conclusion, the hypothesis statements H1, H2, H3, H4, H5, and H6 developed by the authors are accepted.

As per the factors' importance, the authors created a model to enhance the sustainable development of green buildings through innovation hubs in India. Of the factors, government policies and regulations have high significance with a value of 0.709, followed by technological advancements (0.648), market demand (0.619), public-private partnerships (0.527), skilled workforce (0.517), and supply chain efficiency (0.501). These identified factors have a positive influence on the sustainable development of innovation hubs within the green building sector in India.

The significance of the model presented by the authors is that it was created based on the latest studies and primarily focuses on the Indian green construction industry, which is given little attention in many published literatures. This model also includes the priority of each factor, which helps stakeholders to prioritize the factors. Factors such as government policies and regulations, technological advancements, and market demand strongly influence sustainable development. Government policies and regulations (0.709) help to set up standards to achieve high energy efficiency, handle waste and utilize sustainable materials, which integrates with the innovation hub to match the goals of companies with sustainable development goals. Technological advancements (0.648) help to develop smart building systems, technologies utilizing renewable energy and advanced building techniques, which decrease environmental impact. Furthermore, rising market demand (0.619) for adopting eco-friendly and energy-efficient buildings encourages innovation hubs to emphasize green technologies and practices which contribute to sustainable development. Altogether, these factors help in continuous improvement in ensuring sustainable innovation hubs in the green building sector of India. The remaining factors, like public-private partnerships, skilled workforce and supply chain efficiency, also moderately shape the sustainable innovative hubs in green buildings of India. Public-private partnerships help collaboration between both sectors to share resources, knowledge, and financial resources for sustainable development. To manage this factor, the authors give the following recommendations.

- Introduce green financing initiatives, such as green bonds and loans for sustainable projects, which help reduce financial burden.

- Increase community engagement and conduct various awareness campaigns to ensure sustainability initiatives are adopted.
- Through collaboration between the private and public sectors, allocate financial resources to encourage R&D initiatives, which helps to develop innovative green technologies.

Figure 3 presents a model that includes the priority of each factor and required recommendations to effectively improve the sustainable development of green buildings through innovation hubs within India.

Highly skilled workers help carry out advanced and complex projects with high efficiency and productivity. They can troubleshoot any problems that occur and fully utilize the benefits of advanced technologies. To manage this factor, the authors propose the following recommendations.

- Periodically organize training programs for workers, which helps them to update their knowledge and skills in implementing sustainable practices.
- Conduct apprenticeship and mentorship programs to train new workers under the supervision of highly skilled workers.
- From partnership between industry and academic institutions to introduce a curriculum focusing on green building practices and its associated opportunities.

An efficient supply chain helps deliver the required raw materials on time through eco-friendly transportation with reduced waste and environmental impact. To handle this factor, the authors provide the following recommendations.

- Use modular construction methods and pre-fabrication techniques to decrease waste and enhance resource efficiency.
- Implement effective and digitalized inventory management that regularly updates the information about raw materials, which helps decrease waste and carbon emissions.
- Enact a code of conduct to be followed by suppliers, which will help promote ethical practices and ecologically responsible sourcing of raw materials.

The practical implications of the research are diverse. Firstly, it helps the policy-makers understand the significance of the factor “government policies and regulations” and develop a new policy framework that aligns with sustainability goals. Secondly, it helps the stakeholders of the green building industry to understand the various factors that influence green building construction through sustainable innovation hubs with priority. This helps to shift their focus to the most significant factors and increase the productivity of the company. Additionally, in other written literature, there is a general introduction about the role of innovation hubs in green buildings and sustainability, while the authors of this research mainly focus on the application of innovation hubs in the green building sector in maintaining sustainability, which helps to understand the development in the Indian market scenario. The data analysis techniques used, like the chi-squared test and Spearman correlation, help to identify the relation between identified factors and the level of significance, which is absent in most of the written literature. Based on these findings, the authors were able to develop a model that influences sustainable innovation hubs in the green building industry of India.

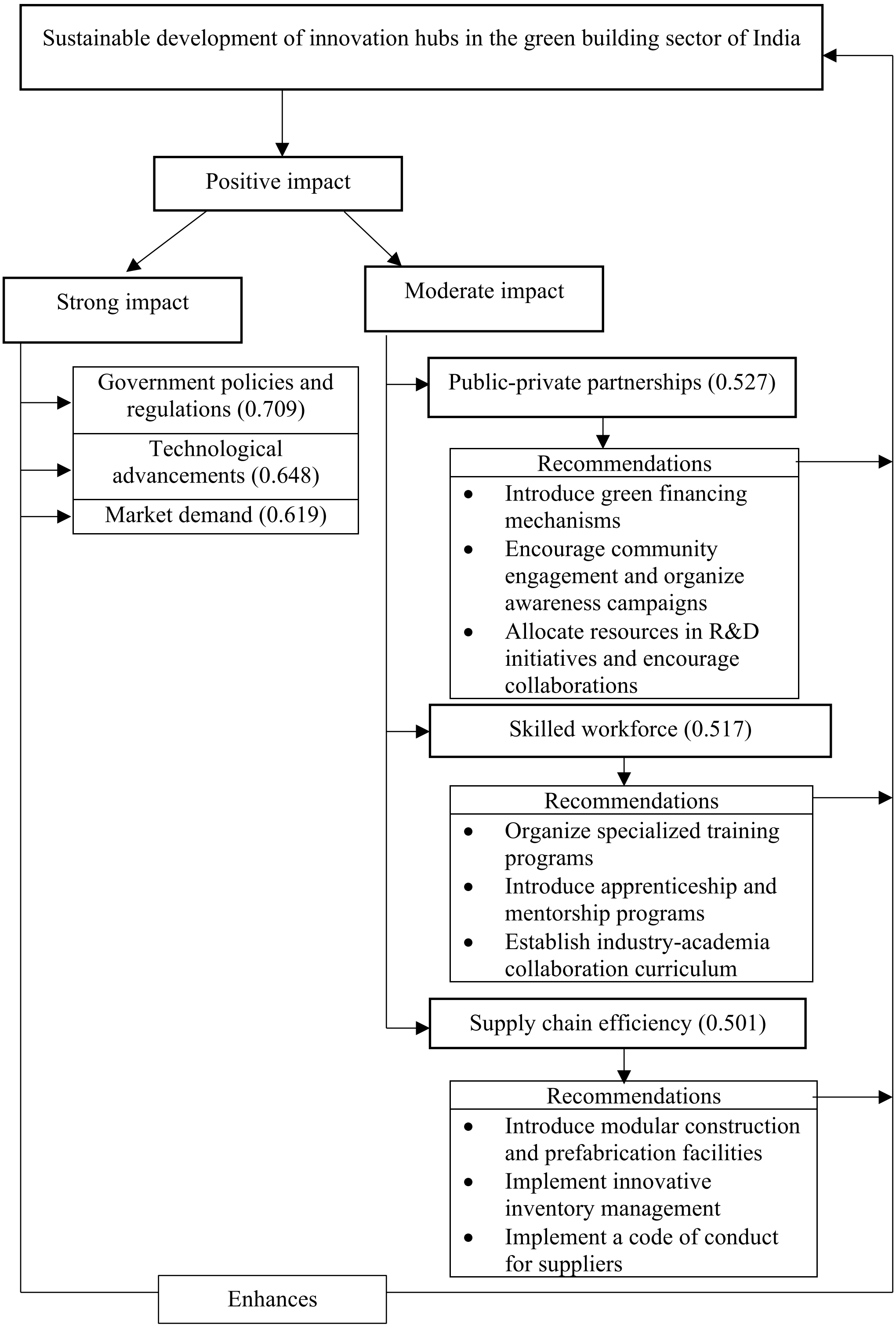

Fig. 3. The model to enhance sustainable development of innovation hubs within the green building sector in India (created by authors).

The authors encountered various limitations during the research. Due to time limitations, the authors collected only 150 sample sizes. As the sample size increases, the occurrence of bias is reduced. Therefore, there is a chance of bias in survey findings. The geographical location selected was in various parts of India, which also may introduce bias as Indian people all over the nation have different beliefs and cultures.

CONCLUSIONS

Indian country is currently undergoing a transition towards eco-responsible and energy-efficient building practices through sustainable innovation hubs in the green building construction sector. These innovation hubs help to adopt advanced technologies and eco-friendly construction solutions by increasing collaborations between building contractors, engineers, architects, researchers and other related policymakers. This helps to reduce carbon footprint and environmental impact. The authors performed a detailed literature review and data analysis methods; six major factors are identified that influence the sustainable innovation hubs in the green building sector. They are government policies and regulations (0.709), technological advancements (0.648), market demand (0.619), public-private partnerships (0.527), skilled workforce (0.517), and supply chain efficiency (0.501). This is followed by the development of a model for the enhancement of sustainable development of innovation hubs in the green construction sector in India.

The authors proposed various recommendations to both future researchers and stakeholders of the construction sector. Future researchers should utilize other statistical techniques such as multiple linear regression, factor analysis along with the chi-squared test and Spearman correlation analysis to enhance the results. They should increase the survey respondent count to reduce the presence of bias. Future researchers should consider this research as a base model and broaden the investigation by considering other countries and related case studies. The stakeholders must adopt the model suggested by the authors to enhance sustainable development. They should invest funds in green technologies and R&D programs to develop new innovative technologies. Stakeholders of the green building construction sector within India should implement real-time data analytics to monitor the progress of sustainable development.

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