DEVELOPMENT OF A FRAMEWORK FOR INDIAN GREEN BUILDING RATING SYSTEM

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DEVELOPMENT OF A FRAMEWORK FOR INDIAN GREEN BUILDING RATING SYSTEM

by

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Submitted

In fulfillment of the requirements of the degree of Doctor of philosophy

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Dedicated to my beloved Parents, Husband &

Teachers

CERTIFICATE

This is to certify that the thesis entitled, "**Development of a Framework for Indian Green Building Rating System**" being submitted by **Mrs. Gayatri Sachin Vyas** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a bonafide record of research work carried out by her under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirement for the degree of Doctor of Philosophy.

The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

The construction industry is responsible for some of the most severe forms of local and global pollution, whose effects include climate change. So, it faces pressure to mitigate such negative impacts through increasing the sustainability of building practices, as reflected in the development of green building (GB) rating systems. Existing rating methods can be applied to different regions by addressing additional aspects such as varied climatic conditions and regional variations. This study proposes a rating system for the Indian context. To achieve this aim and promote GB construction, the study set five objectives: (1) to identify and evaluate various attributes for measuring the greenness of a building, (2) to develop a GB rating framework consisting of components, attributes and parameters to evaluate the green building index (GBI) and thereby rate a building for its greenness, (3) to identify the cost of a GB, (4) to benchmark GB attributes, and (5) to evaluate GB attributes by the environmental, social, and economic pillars of sustainability. For the sake of convenience, these objectives are achieved in five phases based on various research methods, including principal component analysis (PCA), analytical hierarchy process (AHP), fuzzy measures, fuzzy integrals, data envelopment analysis (DEA), and entropy.

The PCA has extracted nine components and 34 attributes. These are used for developing a framework for measuring the greenness of building in developing countries such as India. The nine components are: (1) site selection, (2) environment, (3) building resources and reuse, (4) building services and management, (5) innovative construction techniques, (6) environmental health and safety, (7) mechanical systems, (8) indoor air quality, and (9) economy. The GB rating system developed consists of the GBI at the top level, nine components at the middle level, and 34 attributes at the bottom level. To measure the attributes, 68 parameters were determined. The rating system was converted into a user-

friendly JAVA based software, which makes it easy to implement.

To promote the GB, it is vital to focus on those attributes which cost less while contributing more towards reducing the negative impact of construction on the environment. The outcomes of this study showed that investing in green building is economically profitable as it saves the emission of carbon dioxide (CO_2). The financial analysis of GB projects demonstrated that the percentage increase in the cost for a five stars green rating for integrated habitat assessment (GRIHA) rated buildings varied from 6.43% to 16.35% with an average of 8.50%. In the case of three star rated buildings, the percentage increase in the cost varied from 1.63 to 3.63% with an average of 2.85%. From the study, it was observed that the average payback period for GBs rated three stars was 2.53 years and for GBs rated five stars it was 5.5 years. The average discounted period for a five stars GB was 5.23 years and for a three stars GB, 7.56 years. The increase in cost per square meter for a five stars GB varied from Rs. 827.56 to Rs. 2280.51 and the average increase was Rs. 1,375.91. The increase in cost per square meter for three stars GBs was from Rs. 512.25 to Rs. 1250.09 and the average increase was Rs. 800.16.

The DEA benchmarked those GB attributes which can give more green points using limited funds. These include operation and maintenance costs, material recycling, low-impact construction site techniques, locally available materials, soil pollution, light pollution, plantation of adaptive plants, integrated project management–building information modelling (BIM), environmental impact of materials, and a noise pollution efficient frontier.

However, if the users do not want to focus on the cost parameter alone, they may also consider the environmental and the social pillars of sustainability. In that case, the most substantial attributes are the occupant’s health, safety, and comfort, climatic conditions, the cost of investment, operation and maintenance, and indoor air quality.

So the study contributes to theory and practice in the form of models and methods to

(1) assess the GB in India by JAVA based software; (2) find out the increase in initial cost, payback period, and life cycle cost of a GB; (3) identify the GB attributes through which a GB developer can achieve more green points with less cost; and (4) identify prominent attributes by considering social, environmental, and economic pillars of sustainability.

The proposed approach can produce significant benefits for GB construction practices that are not likely to result from conventional practices. Further, the framework suggested in this research can be applied for countries having similar climatic conditions. The findings of this study can aid designers and developers in their quest to achieve green development.

Keywords: Green Building; Rating System; Sustainable Development; Principal Component Analysis; Analytical Hierarchy Process; Fuzzy Integral; Data Envelopment Analysis; Initial Cost; Payback Period.

सार

निर्माण उद्योग, स्थानीय और वैश्विक प्रदूषण के कुछ सबसे गंभीर रूपों के लिए जिम्मेदार है, जिनके प्रभाव में जलवायु परिवर्तन शामिल है इसलिए, यह ग्रीन बिल्डिंग (जीबी) रेटिंग सिस्टम के विकास में परिलक्षित किए गए निर्माण विधियों की स्थिरता में वृद्धि के माध्यम से इस तरह के नकारात्मक प्रभावों को कम करने के लिए दबाव का सामना करना पड़ता है। विभिन्न मौसम संबंधी स्थितियों और क्षेत्रीय विविधताओं जैसे अतिरिक्त पहलुओं को संबोधित करके मौजूदा रेटिंग विधियों को अलग-अलग क्षेत्रों में लागू किया जा सकता है। इस अध्ययन में भारतीय संदर्भ के लिए एक रेटिंग प्रणाली का प्रस्ताव है। इस उद्देश्य को हासिल करने के लिए और जीबी निर्माण को बढ़ावा देने के लिए, अध्ययन में पांच उद्देश्यों की स्थापना की गई: (१) एक इमारत की ग्रीननेस की पहचान और मूल्यांकन करने के लिए विभिन्न कारकों की पहचान, (२) मूल्यांकन के लिए घटकों, विशेषताओं और मापदंडों से युक्त जीबी रेटिंग ढांचे का विकास ग्रीन बिल्डिंग इंडेक्स (जीबीआई) और इसकी ग्रीननेस के लिए एक इमारत की दर, (३) जीबी की लागत, (४) बेंचमार्क जीबी कारक, और (५) पर्यावरण, सामाजिक, और आर्थिक, तीन स्थिरता के खम्भों द्वारा जीबी कारकों का मूल्यांकन. इन उद्देश्यों को पांच चरणों में हासिल किया जाता है, जिसमें प्रमुख घटक विश्लेषण (पीसीए), विश्लेषणात्मक पदानुक्रम प्रक्रिया (एएचपी), फजी उपाय, फजी एकीकृत, डेटा भंग विश्लेषण (डीईए) और एन्ट्रापी सहित विभिन्न शोध विधियों पर आधारित है।

पीसीए ने ९ घटकों और ३४ विशेषताओं को निकाला है। इनका उपयोग भारत जैसे विकासशील देशों में निर्माण की ग्रीननेस को मापने के लिए एक ढांचा विकसित करने के लिए किया जाता है। नौ घटक हैं: (१) स्थान चयन, (२) पर्यावरण, (३) निर्माण संसाधन और पुन: उपयोग, (४) निर्माण सेवाओं और प्रबंधन, (५) अभिनव निर्माण तकनीक, (६) पर्यावरण स्वास्थ्य और सुरक्षा, (७) मैकेनिकल सिस्टम, (८) इनडोर हवा की गुणवत्ता, और (९) अर्थव्यवस्था विकसित जीबी रेटिंग प्रणाली में शीर्ष स्तर पर जीबीआई, मध्य स्तर पर नौ घटक होते हैं, और नीचे के स्तर पर ३४ विशेषताएँ होती हैं। गुणों को

मापने के लिए, ६८ पैरामीटर निर्धारित किए गए थे। रेटिंग प्रणाली को उपयोगकर्ता के अनुकूल जावेवा आधारित सॉफ़्टवेयर में बदल दिया गया था, जिससे इसे लागू करना आसान हो जाता है।

जीबी को बढ़ावा देने के लिए, उन विशेषताओं पर ध्यान केंद्रित करना महत्वपूर्ण है, जो खर्च कम और पर्यावरण पर निर्माण के नकारात्मक प्रभाव को कम करने के लिए अधिक योगदान करते हैं। इस अध्ययन के परिणामों से पता चला है कि हरी इमारत में निवेश करना आर्थिक रूप से लाभदायक है क्योंकि यह कार्बन डाइऑक्साइड (सीओ २) का उत्सर्जन बचाता है। जीबी परियोजनाओं का वित्तीय विश्लेषण दर्शाता है कि एकीकृत आवास मूल्यांकन (जीआरआईएचए) के पांच सितारों के हरे रंग की रेटिंग के लिए लागत में प्रतिशत वृद्धि दर ८.५३% से औसत ६.४३% से बढ़कर १६.३५% हो गई है। तीन सितारा श्रेणी निर्धारण वाली इमारतों के मामले में, लागत में प्रतिशत वृद्धि १.६3 से ३.६३% से बढ़कर औसत २. ८५% हो गई है। अध्ययन से, यह देखा गया कि तीन सितारों को रेट किए गए जीबी के लिए औसत लौटाने का समय २.५३ साल था और पांच साल के लिए जीबी का मूल्यांकन ५.५ साल था। पांच सितारे जीबी की औसत रियायती अवधि ५.२३ साल थी और तीन सितारों के लिए जीबी, ७.५६ साल थी। पांच सितारे जीबी के लिए लागत प्रति वर्ग मीटर में वृद्धि ₹ ८२७.५६ से ₹ २२८0.५१ और औसत वृद्धि ₹ १, ३७५.९१ थी । तीन सितारों के लिए प्रति वर्ग मीटर की लागत में वृद्धि रुपये से थी। ₹ ५१२.२५ से ₹ १२५0.0९ और औसत वृद्धि ₹ ८00. १६ थी।

डीईए ने उन जीबी गुणों को बेंचमार्क किया जो कि सीमित निधियों का उपयोग करके अधिक हरे रंग का अंक दे सकते हैं। इसमें संचालन और रखरखाव लागत, सामग्री रीसाइक्लिंग, कम प्रभाव वाली निर्माण साइट तकनीक, स्थानीय रूप से उपलब्ध सामग्री, मिट्टी प्रदूषण, प्रकाश प्रदूषण, अनुकूली पौधों के पौधरोपण, एकीकृत परियोजना प्रबंधन-निर्माण सूचना मॉडलिंग (बीआईएम), सामग्री का पर्यावरणीय प्रभाव और एक शोर प्रदूषण कुशल सीमा हालांकि, अगर उपयोगकर्ता अकेले लागत पैरामीटर पर ध्यान केंद्रित नहीं करना चाहते हैं, तो वे पर्यावरण और स्थायी स्थिरता के सामाजिक खंभे

पर भी विचार कर सकते हैं। उस मामले में, सबसे महत्वपूर्ण गुणों में रहने वाले के स्वास्थ्य, सुरक्षा, और आराम, जलवायु परिस्थितियां, निवेश की लागत, संचालन और रखरखाव, और इनडोर हवा की गुणवत्ता है।

अतः यह अध्ययन सिद्धांत और व्यवहार के लिए मॉडलों और तरीकों के रूप में योगदान देता है (१) जावा के सॉफ्टवेयर द्वारा भारत में जीबी का मूल्यांकन; (२) प्रारंभिक लागत में बढ़ोतरी, लौटाने की अवधि, और जीबी के जीवन चक्र की लागत का पता लगाएं; (३) जीबी एट्रिब्यूट्स की पहचान करें जिसके माध्यम से एक जीबी डेवलपर कम लागत के साथ अधिक हरे रंग की अंक प्राप्त कर सकता है; और (४) स्थिरता के सामाजिक, पर्यावरण और आर्थिक खंभे पर विचार करके प्रमुख विशेषताओं की पहचान करें।

प्रस्तावित दृष्टिकोण जीबी निर्माण प्रथाओं के लिए महत्वपूर्ण लाभ उत्पन्न कर सकते हैं जो पारंपरिक प्रथाओं से होने की संभावना नहीं है। इसके अलावा, इस शोध में सुझाए गए ढांचे के समान जलवायु परिस्थितियों वाले देशों के लिए लागू किया जा सकता है। इस अध्ययन के निष्कर्ष अभिकल्पकार और विकासक को हरे रंग के विकास को हासिल करने के लिए अपनी खोज में मदद कर सकते हैं।

कुंजी शब्द : ग्रीन बिल्डिंग; रेटिंग प्रणाली; सतत विकास; प्रमुख कंपोनेंट विश्लेषण; विश्लेषणात्मक पदानुक्रम प्रक्रिया; फजी इंटीग्रल; आकड़ा लपेटना विश्लेषण; आरंभिक लागत; ऋण वापसी की अवधि।

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LIST OF ABBREVIATION

AAC	Autoclaved Aerated Concrete
ABGR	Australian Building Greenhouse Rating
AHP	Analytical Hierarchy Process
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BEE	Bureau of Energy Efficiency
BIM	Building Information Modelling
BIPV	Building Integrated Photovoltaic
BMVBS	Federal Ministry of Transport, Building and Urban A airs
BOMA	Building Owners and Managers Association
BOQ	Bill of Quantity
BRE	Building Research Establishment
BREEAM	Building Research Establishment's Environmental Assessment Method
BRR	Building Resource and Reuse
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CB	Commercial Building
CCR	Charnes-Cooper- Rhodes
CFL	Compact Fluorescent Light
CI	Consistency Index
CPA	Comprehensive Project Evaluation
CPCB	Central Pollution Control Board
CPI	Cost Performance Index
CPWD	Central Public Works Department
CR	Consistency Ratio
CRS	Constant Returns to Scale
CURC	Coal Utilization Research Council
DEA	Data Envelopment Analysis
DGNB	Deutsche Gesellschaftfür Nachhaltiges Bauen
DMU	Decision Making Unit
DNGB	German sustainable Building Council
DSR	Delhi Schedule of Rates
EAM	Environment Assessment Method
ECBC	Energy Conservation Building Code
EG	Extremely Good
EI	Extremely Important
EMS	Efficiency Measurement System
ENVIS	Environmental Information System
EP	Extremely Poor
EPI	Energy Performance Index
ESRC	Economic and Social Research Council

EUI	Extremely Unimportant
FST	Fuzzy Set Theory
GB	Green Building
GBI	Green Building Index
GDP	Gross Domestic Product
GeSBC	German Sustainable Building Certificate
GHEM	Green Home Evaluation Manual
GRIHA	Green Rating for Integrated Habitat Assessment
HK-BEAM	The Hong Kong Building Environmental Assessment Method
HK-BEAM	Hong Kong Building Environmental Assessment Method
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IB	Institutional Building
IEA	International Energy Agency
IGBC	Indian Green Building Council
IIEC	International Institute for Energy Conservation
IPCC	Intergovernmental Panel for Climate Change
IS	Indian Standard
ISO	International Organisation for Standardization
IUCNs	International Union for Conservation of Nature and Natural Resources
KMO	Kaiser-Meyer-Olkin
LC	Life Cycle
LCC	Life Cycle Cost
LCD	Liquid Crystal Display
LEED	Leadership in Energy and Environmental Design
LG	Little Good
LI	Little Important
LP	Little Poor
LUI	Little Un-Important
MATLAB	Matrix Laboratory
MCDM	Multiple Criteria Decision Making
MNRE	Ministry of New and Renewable Energy
MoEF	Ministry of Environment and Forests
MSA	Measures of Sampling Adequacy
N	Neutral
NAHB	National Green Building Standard
NBC	National Building Code
NCF	Net Cash Flow
NPV	Net Present Value
NR	Non-Rated
O&M	Operational and Maintenance
PC	Principal Components
PCA	Principal Component Analysis
PV	Photovoltaic

RTI	Right to Information
SBTool	Sustainable Building Tool
SBS	Sick Building Syndrome
SD	Sustainability development
SPSS	Statistical Package for the Social Sciences
SRI	Solar Reflective Index
STP	Science and Technology Park
TERI	The Energy and Resources Institute
UNFCCC	United Nations Framework Convention on Climate Change
USGBC	United States Green Building Council
VG	Very Good
VI	Very Important
VOC	Voltaic Organic Compounds
VP	Very Poor
VUI	Very Un-Important
WCED	World Commission on Environment and Development
WSM	Weighted Sum Method