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A Methodological Framework for Life Cycle Sustainability Assessment of Construction Projects Incorporating TBL and Decoupling Principles

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Abstract: The triple bottom line (TBL) principle encompasses the idea of continued economic and social well-being with minimal or reduced environmental pressure. However, in construction projects, the integration of social, economic, and environmental dimensions from the TBL perspective remains challenging. Green building rating tools/schemes, such as Green Rating for Integrated Habitat Assessment (GRIHA), Leadership in Energy and Environment Design (LEED), Building Research Establishment Environment Assessment (BREEAM), and their criteria, which serve as a yardstick in ensuring sustainability based practices and outcomes, are also left wanting. These green building rating tools/schemes not only fail to comprehensively evaluate the three dimensions (social, economic, and environment) and interaction therewith, but also lack in capturing a life cycle approach towards sustainability. Therefore, this study intends to address the aforementioned challenges. The first part of this study presents the concept of sustainable construction as a system of well-being decoupling and impact decoupling. Findings in the first part of this study provide a rationale for developing a methodological framework that not only encapsulates a TBL based life cycle approach to sustainability assessment in construction, but also evaluates interactions among social and economic well-being, and environmental pressure. In methodological framework development, two decoupling indices were developed, namely, the phase well-being decoupling index ($PWBDI_K$) and phase impact decoupling index ($PIDI_K$). $PWBDI_K$ and $PIDI_K$ support the evaluation of interdependence among social and economic well-being, and the environmental pressure associated with construction projects in different life cycle phases. The calculation underpinning the proposed framework was illustrated using three hypothetical cases by adopting criteria from GRIHA Precertification and GRIHA v.2019 schemes. The results of these cases depict how the interactions among different dimensions (social, economic, and environment) vary as they move from one phase to another phase in a life cycle. The methodological framework developed in this study can be tailored to suit the sustainability assessment requirements for different phases and typologies of construction in the future.

Keywords: triple bottom line (TBL); green building rating tools; sustainability assessment; sustainable construction; life cycle assessment; decoupling

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1. Introduction

Sustainability considerations in the building and construction (B&C) sector are becoming more important due to increasing international pressure to address the UN's Sustainable Development Goals (SDGs), a universal framework for sustainable development that revolves around people, planet, and prosperity [1]. The building and construction sector impacts all three dimensions of sustainability; namely, social, environmental, and economic, also known as the triple bottom line (TBL). Social impact by creating spaces to live and work in, economic impact by contributing to gross domestic product (GDP) and creating jobs, and environmental impact due to the usage of resources and raw materials and the generation of construction and demolition (C&D) waste during the processes of construction [2–4]. C&D is the industry term for end of life determination of building and construction materials, although increasingly from a circular economy perspective, this term may considered as deconstruction instead. Buildings/constructed facilities may last 80–100 years or more, and they need to be maintained throughout their life cycle. The operation, maintenance, and decommissioning phases of a constructed facility also have social impact, through the wellbeing of spaces and improvement in productivity, etc.; economic impact through procurement costs, operational costs, job opportunities, etc.; and environmental impact through the use of energy, water, waste generation, etc. However, the pace of the B&C sector in adopting life cycle cum TBL based sustainability practices is slow [5].

In delivering TBL based sustainability outcomes, the implementation of green/sustainable building and construction assessment tools/schemes may be helpful [3,6]. Green Rating for Integrated Habitat Assessment (GRIHA-India), Leadership in Energy and Environment Design-Indian Green Building Council (LEED-IGBC-India), Green Star-Australia, Building and Construction Authority Green Mark (BCA Green Mark-Singapore), Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB-Germany), Comprehensive Assessment System for Built Environment Efficiency (CASBEE-Japan), Building Research Establishment Environment Assessment (BREEAM-UK), Green Globes-Canada, Green Building Index (GBI-Malaysia), Global Sustainability Assessment System (GSAS-Gulf countries), and others are some of the popular assessment tools/schemes in different regions and countries of the world. These rating tools/schemes serve as a reference guide to assess the building/constructed facility's sustainability performance. The tools have been developed so as to include a set of parameters that pertain to the design, construction, operation, and maintenance phases of buildings/constructed facilities [7]. However, to ensure continuous delivery of sustainability outcomes, current sustainability assessment tools/schemes need to continuously improve to overcome their various limitations, such as lack of life cycle assessment considerations, a holistic approach, performance orientation, effective communications, continuity, participation, a specific vision, adequate scope, a clear framework and indicators, and others [8–13]. Most of the current assessment tools/schemes award certification to buildings/construction based on a single compiled score, in which the environmental aspect of sustainability dominates the social and economic aspects of sustainability. Within these certification tools/schemes, the life cycle approach should be consistently considered, rather than individual measurements for evaluating the overall performance of construction projects [13]. These assessment systems should be transparent, tailor made, and flexible enough for assessing the sustainability requirements of preconstruction, construction, operation and maintenance, and the decommissioning/deconstruction phases of construction.

Growing acceptance of the life cycle based sustainability approach and its evaluation requires comprehending the relationships and interactions of different dimensions of sustainability by tactically bringing them together. Decoupling analysis is one such tool, which evaluates the quality of economic growth by measuring the coupling between economic growth, and environmental impact and resource use. Decoupling evaluation is at the core of the sustainability framework [14]. Current sustainability assessment frameworks for buildings/construction lacks decoupling evaluation. The majority of previous studies for evaluating decoupling in the B&C sector were at an aggregated industrial level, and evaluated decoupling between two dimensions of sustainability only, i.e., between economic and environment [15–17].

At present, there is no sustainability assessment rating tool/scheme for buildings/construction that explicitly focuses on measuring sustainability from the TBL perspective incorporating decoupling evaluation. Hence, a conceptual sustainability assessment framework needs to be developed, not just for the rating of the constructed facility, but also because of the life cycle of a building. A framework that focuses on a life cycle cum TBL based sustainability approach and, at the same time, ensuring the transition from linear (less sustainable) to circular (more sustainable) systems is critical. Therefore, this research focuses on developing TBL based sustainability assessment framework cutting across different life cycle phases, simultaneously evaluating the transition of linear systems to circular systems using scores obtained from TBL based sustainability assessment at each phase of construction.

The objectives of the current study are as follows:

1. To identify different TBL based sustainability, i.e., social, economic, and environmental, assessment parameters and indicators for the different life cycle phases of a construction.
2. To propose a methodological framework and classification system by integrating TBL based life cycle sustainability parameters and decoupling indices.

Following this introduction, Section 2 critical reviews the current literature on the interaction among different aspects of sustainability, current sustainability assessment frameworks and presents a comparison of ten rating tools from the TBL perspective. In Section 3, the research method is presented. This section offers analysis of the extracted TBL based life cycle sustainability assessment parameters and presents the methodological framework for calculating TBL scores for life cycle phases and decoupling indices. Section 4 focuses on the hypothetical cases, taking GRIHA criteria to illustrate the calculation procedure of decoupling indices developed in the framework. Section 5 provides the conclusion related to this research.

2. Building and Construction Sustainability

2.1. Rethinking Sustainability as a System of Well-Being Decoupling and Impact Decoupling

Construction is critical to the sustainable development framework, as it affects three dimensions of sustainability: social well-being, economic well-being, and environmental pressure [18–20]. Construction has traditionally operated as a "take, make, waste" process, taking raw material from nature, using it in construction and then either abandoning the facility after use or dumping the debris into a landfill. This approach to construction is known as the linear approach to construction. Critical evaluation of current construction processes reveals that they are high on the consumption of resources and pollution creation [21,22]. The net result of this is the increasing scarcity of construction materials and reduction in available natural resources at an alarming rate. Growing concern for the environment, especially in the last few decades, has resulted in several agreements and efforts to define a framework for sustainable development, with an emphasis on concepts such as reduce, recycle, and reuse; more use of green buildings; renewable energy; zero waste; and other such related concepts.

Construction, especially in developing countries, is modelled on a linear approach [23]. The linear approach to construction is characterized by an increase in demand for extracting virgin materials for production and the subsequent construction, operation and maintenance of a project. However, even during/after the construction, operation and maintenance of a project, it continues to impact other aspects of sustainability, i.e., the economic and social. On the economic side, focus is usually on the increase in production profits. With increased production profits, further investment in the economy leads to better job opportunities. In addition, with better job opportunities and economic activities, the socioeconomic gap decreases.

On the contrary, this linear approach further intensifies the extraction of virgin materials and, as a result, sustaining economic and social well-being in the long run is not certain. In a linear approach, social well-being and its improvement are largely dependent on the use of resources from nature and, with an ever increasing population, the use of resources is bound to increase and, as a result, environmental pressure will increase. Economic well-being and growth are also associated with the ever increasing use of resources, resulting in environmental degradation. If continued in the same way, these impacts will lead to disruptions in ecosystem services that are vital to social well-being [14].

To ensure sustainability in the longer run, the vision should not be only aimed at minimizing resource use/resource optimization as this may result in slowing down economic growth [24]. The new systems that enable resource optimization, reduce environmental impacts, and provide alternative economic returns and the social well-being of stakeholders associated with construction, need to be developed [25].

Seeing the nature of the resource intensive construction industry, developing tools for estimating well-being decoupling and impact decoupling and incorporating them in sustainable assessment has become critical to realize the true picture of sustainability (Figure 1). In other words, construction needs assessment models to ensure the decoupling of social and economic well-being from environmental pressures created in different phases of a construction.

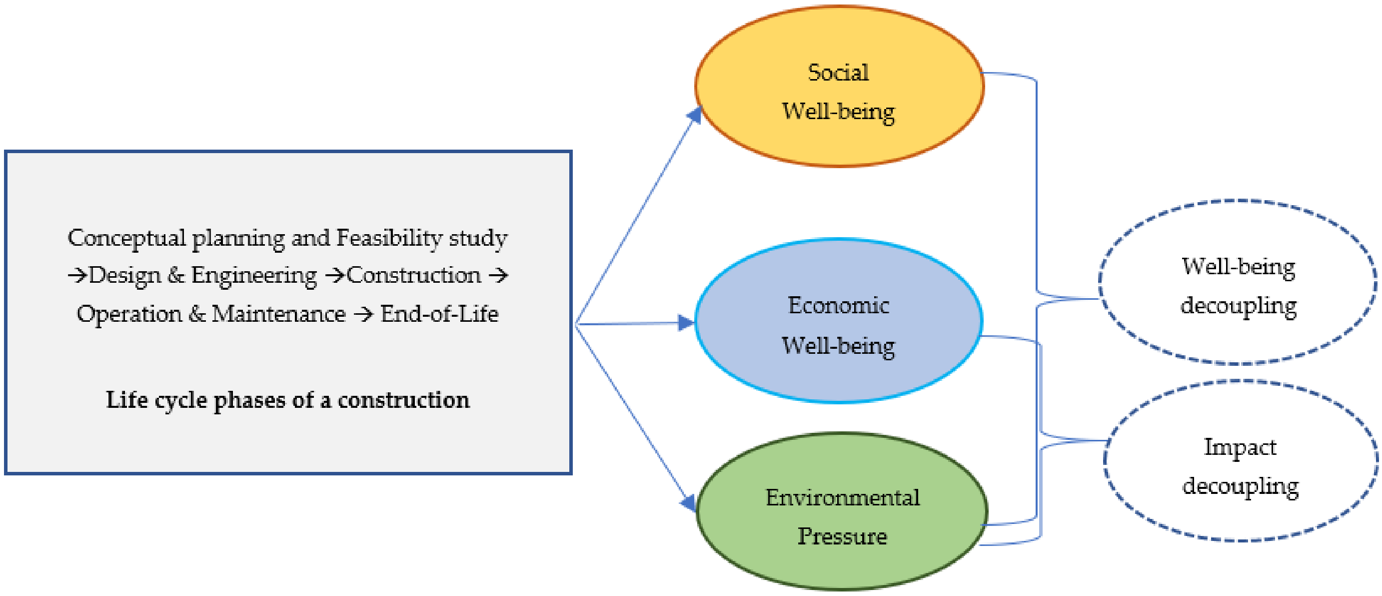

Figure 1. Schematic diagram representing TBL cum decoupling model of sustainability in construction.

2.2. Current Sustainability Assessment Frameworks in Construction

To assess the extent of sustainability compliance, a framework encapsulating sustainability assessment principles and sustainability procedures is required. According to Sala et al., (2015) [8], a framework for sustainability assessment should be based on certain principles, such as: guiding vision (progress towards the goal of delivering well-being should be within planetary limits and ensured for current as well as future generations), essential considerations (incorporating social, economic and environment components and their interactions), adequate scope (progress towards sustainable development should adopt certain timeline, to address both short and long term effects, and it should also capture local as well as global effects), framework and indicators (based on a certain conceptual framework that is to be linked with identified core indicators and reliable data), transparency (the transparency of data and data sources for indicators should be considered), effective communication (clearly communicating with a wide audience and the proper dissemination of results), continuity and capacity (should be continuously monitored and scored), and broad participation (it should encourage legitimacy and relevance by the way of interaction among stakeholders right from the initial stages of the project).

The construction industry, too, has a long history of developing and using such sustainability assessment frameworks [26,27]. Green building councils of different countries are actively involved in developing such frameworks for sustainability assessment schemes. Typically, assessment schemes have been devised using a yardstick for delivering sustainability outcomes through constructed facilities. GRIHA (India), LEED-IGBC (India), Green Star (Australia), BCA Green Mark (Singapore), DGNB (Germany), CASBEE (Japan), BREEAM (UK), Green Globes (Canada), GBI (Malaysia), GSAS (Gulf countries), and others are some of the prevalent assessment tools/schemes. As already mentioned, green rating tools/schemes include a set of parameters and indicators to assess the level of sustainability [7]. Illankoon et al. (2017) [28], after reviewing and comparing eight international green building tools, established seven key criteria in these rating tools as follows: site, energy, water, indoor environment quality, materials, waste and pollution, and management. Other than these key criteria, criteria such as triple bottom line (TBL) reporting, education and awareness, the economic aspects of various costs, sustainable design and planning, and stakeholder engagement can be used to develop new rating tools in the future, as these are missing from the rating tools but illustrated in literature [28].

2.2.1. Critique of Current Sustainability Assessment Frameworks in Construction

Often, the terms green and sustainable construction are used synonymously, but they do have slightly different meanings. As per the US EPA, green building is also referred to as green construction, a structure with an application of processes that are environmentally friendly and resource efficient throughout their life cycle, i.e., during planning, construction, operation, maintenance, renovation, and end of life phases. However, a sustainable building or construction is not only about environmental protection and promoting resource optimization, but should also encompass social well-being factors—such as: (1) security, safety, satisfaction, comfort, and human contributions such as skills, health, knowledge, and motivation [29,30]; (2) people's social–cultural spiritual needs [31]; and (3) education and skill development, equality, health and safety, community engagement and benefits [32]—and economic sustainability parameters, such as: (1) monetary gains to the stakeholders from the project [33]; (2) growth, efficiency and stability [34]; and (3) employment and economic opportunities [35]. A sustainability framework in construction should be based on the fact that construction activities should be socially, economically, and environmentally safe [28].

Critical evaluation of ten rating tools/schemes reveals that most of them deliver a single rating to construction projects after evaluating them against a predetermined set of sustainability parameters that are mostly dominated by environmental parameters. Most of these rating tools/schemes are biased towards evaluating environmental sustainability, whereas economic and social aspects are partially neglected [28]. Though most of the rating tools/schemes consider social dimensions by allocating 25% of the credit points on average, economic sustainability is rarely evaluated. The DGNB (Germany) rating system gives substantial weightage to economic sustainability by allocating 30% of the credit points, in comparison to other tools (Table 1).

Table 1. Weights of TBL (social, economic, and environment) credits in different rating tools/schemes.

Building Assessment Tools	Social	Economic	Environment
GRIHA (India)	24	5	71
LEED-IGBC (India)	18	—	82
Green Star (Australia)	31	—	69
Green Mark (Singapore)	18.8	—	81.2
DGNB (Germany)	30	30	40
* CASBEE (Japan)	28.8	6.2	65
BREEAM (UK)	26	12	62
Green Globes (Canada)	22	—	78
GBI (Malaysia)	28	1	71
GSAS (Gulf)	28	3	69

* Refer to Appendix A for methodology and detailed division of credits from TBL considerations in different rating tools/schemes. * CASBEE (Japan): It does not allocate any credit points; it calculates built environment efficiency (BEE) as the ratio of environmental quality of a building to an environmental load of a building.

The rationale for focusing more on environmental sustainability is that once environmental sustainability criteria are satisfied then social and economic aspects will be taken care of [36]. Moreover, some of the researchers claim that most rating tools/schemes fail to capture a TBL based perspective on sustainability [10]. The lack of consideration of social and economic dimensions in building performance during its life cycle leads to a deviation from the true meaning of sustainability. Most of the assessment tools and respective criteria (credits) are concerned with the design, construction, and operation and maintenance phases of a project; conception and demolition/decommissioning are not explicitly considered [37].

Life cycle sustainability assessment (LCSA) is defined as the evaluation of environmental, social, and economic negative impacts and benefits that occur through decision-making processes, towards more sustainable projects/products throughout the life cycle of projects/products [38] (Equation (1)).

$$LCSA = f(Soc - LCA + Eco - LCA + Env - LCA) \quad (1)$$

where,

Soc-LCA = f (social assessment parameters, conceptual planning and feasibility study, design and engineering, construction, operation and maintenance, and end-of-life);
Eco-LCA = f (economic assessment parameters, conceptual planning and feasibility study, design and engineering, construction, operation and maintenance, and end-of-life); and
Env-LCA = f (environment assessment parameters, conceptual planning and feasibility study, design and engineering, construction, operation and maintenance, and end-of-life)

Life cycle sustainability assessment/management is missing from such tools/schemes. In a review paper, Wulf et al. (2019) [39] found that, in recent years, with respect to LCSA, the focus has been more on case studies and less on developing methodological frameworks. Sala et al. (2013) [40], in their study, advocate the development of a methodology that adopts a holistic approach and has the capacity to address general or complex system theory. Critical topics that need to be addressed in developing an LCSA based methodological framework should include the development of quantitative and practical indicators for Soc-LCA, approaches to assess the scenarios from a life cycle perspective, standardizing methods to include uncertainties, synergies, and tradeoffs between different dimensions of sustainability [41,42]. Although the literature shows TBL perspectives have been gradually adopted, in-depth investigation of environmental, economic, and social holistically is still missing [4].

Any kind of sustainable assessment and management of construction requires close coordination and interactions among internal and external stakeholders that are associated with the construction project life cycle phases, otherwise, the assessment becomes too theoretical [43–45].

Another aspect that is critical for LCSA is decoupling analysis. "Decoupling" as a term was first advanced by the OECD in 2001; it highlights the concept of continued socio-economic growth with diminishing environmental impacts. Decoupling and its evaluation, which is at the core of the sustainability framework [14], is missing from such rating tools/schemes, though the underlining principles of sustainability assessment overlap with decoupling. Central to the UN SDGs/Agenda 2030, decoupling serves as a foundation for materializing the overarching framework of sustainable development; without decoupling the UN SDGs will not be achievable [46].

Current research challenging existing LCSA frameworks call for (1) adopting a holistic approach towards understanding the dynamic interactions between different dimensions of sustainability, (2) shifting from multidisciplinary to transdisciplinary approaches, (3) capability of moving forward through visions and goals, (4) continuous social learning for the stakeholders, and (5) probabilistic approach for dealing with uncertainties [8].

Based on the above critiques, at present, the current rating tools/schemes for supporting sustainability outcomes are left wanting, as they do not deal with all the aspects of

TBL and interactions thereof. Moreover, real world, i.e., industry practices, have also not presented as a way forward in supporting TBL based sustainability outcomes. Hence, the current study puts forward a methodological LCSA framework that focuses on TBL based sustainability outcomes and, at the same time, ensures the transition from less sustainable (coupled) systems to more sustainable (decoupled) systems.

3. Research Method

This research is designed in three parts, as shown in Figure 2. In part 1, the study commences with a review of the current green/sustainability rating tools/schemes from the TBL perspective by examining each of the assessment parameters of these rating tools/schemes and classifying them under environment, social or economic categories. It presents a critique of current sustainability assessment frameworks in construction and then establishes the need for the present study.

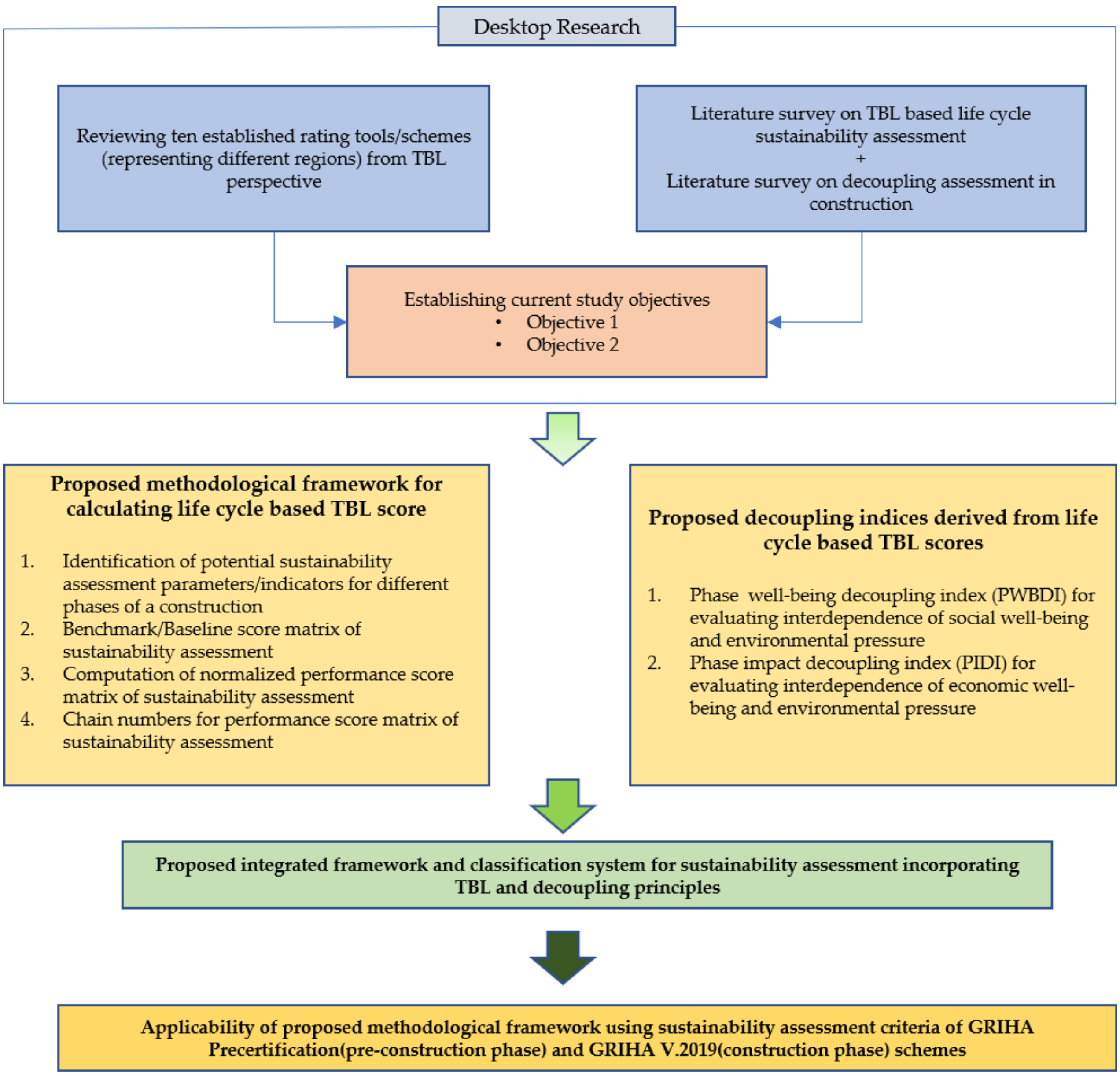

Figure 2. Research methodology flowchart.

In part 2, the extraction, integration, and identification of potential TBL based sustainability assessment parameters from different sources, cutting across different life cycle phases (conceptual planning and feasibility, design and engineering, construction, operation and maintenance, end of life) of a construction project, are presented. In addition, a new methodological framework for the LCSA of construction, incorporating TBL and decoupling principles, is presented in this part. This part also presents the key steps involved in computing TBL scores and decoupling indices for different phases, and a classification system for mapping construction projects using computed TBL scores and decoupling indices.

In part 3, the application of the proposed methodological framework using the sustainability assessment criteria of GRIHA Precertification and GRIHA v.2019 schemes are presented, and calculations are shown for computing decoupling indices (well-being and impact decoupling indices) using three hypothetical cases, followed by conclusions and limitations of this research.

3.1. Extraction of Life Cycle Based TBL Sustainability Assessment Parameters

TBL based sustainability parameters and their potential indicators were extracted from previous works. Sustainability parameters and their indicators are prerequisites for any sustainability assessment, as they are critical for setting/translating into sustainability targets [8] (Sala et al., 2015). Based on this argument, the sustainability assessment parameters for different construction phases, along with their description and potential indicators, were identified through a sequential literature review (SLR). A similar approach was used by Stanitsas et al. (2020) [47], to identify the sustainability indicators for the management of construction projects. These identified parameters are knowingly put at a higher level with fewer details about their indicators, as there can be numerous potential indicators under each of the sustainability assessment parameters. The selection of indicators depends on various factors based on regional context, and may not be globally accepted. Tables 2–4 present the holistic view of TBL based sustainability assessment parameters that are relevant to different phases of a construction project. This set of identified parameters form the rationale for developing an integrated framework and classification system for sustainable construction, incorporating TBL and decoupling principles.

Table 2. Pool of relevant social based sustainability assessment parameters for different phases of construction.

Social Sustainability Parameters (Phase 1. Conceptual Planning and Feasibility Study)			
Parameters	**Description**	**Indicators**	**References**
Stakeholders' consultation and engagement	Consultation and engagement with stakeholders/affected communities to identify and monitor their concerns and opportunities in different phases of construction	Consultation/engagement report based on parameters such as: expectations, project constraints, partnership, safety, employment, training, accessibility, and others *	[48–58]
Health and safety considerations	Planning for health and safety issues related to workers (including female workers), users, and other stakeholders	Considerations of guidelines related to health and safety of the stakeholders, which can be documented in the form of Health Impact Assessment (HIA) *	[52,53,57,59–61]
Ethical considerations	Planning to promote and ensure professional ethics, avoiding ethical dilemmas, dealing with conflicts of interest, and others	Adopting a framework for monitoring and ensuring compliance to ethical practices *	[62–67]

Table 2. *Cont.*

Social Sustainability Parameters (Phase 2. Design and Engineering)			
Parameters	**Description**	**Indicators**	**References**
Decent work and economic growth	Incorporate policies for creating job opportunities in neighborhood communities, maintaining social and demographic equity in the design team, construction workers, and others involved in different life cycle phases	Adopting/implementing framework for assessing the trends in the stocks of natural resources, emissions, and discharges in the environment resulting from economic activities; accounting of environmental preservation cost and conservation cost	[1,68,69]
Health, well-being, and the environment	Design for better health, outdoor/indoor environments that promotes better lifestyle practices, nutrition, social connectivity, minimized infectious disease transmission, and others	Adopting design considerations such as: universal accessibility and sustainable transportation, resilient buildings and infrastructure, high quality public and green spaces, good mental health, and others *	[68–70]
Design with socioeconomic consideration	Design for promoting culture of occupational health (physical and mental), safety, social inclusion of workers, and include labor provisions in tendering process and supplier contracts	Adopting design considerations such as: design for safety and sanitation for construction workers, design for dedicated facilities for service staff, design for the positive social impact, which include provisions for promoting gender equality, protecting labour rights, and others	[68,71]
Long term value to the society and enhancing local quality of life	Designs considering physical and environmental impacts on the local area, taking community input for improving community's health	Adopting a framework for evaluating social value to the society	[68,69]
Prioritizing occupant's comfort	Designs with considerations for environment that is comfortable to occupant	Adopting guidelines of ASHRAE standards for the design of high performance green buildings, which include: thermal comfort, natural and energy efficient lighting, acoustic comfort, olafactory, ergonomics, and visual comforts in designs	[68,72]
Social Sustainability Parameters (Phase 3. Construction)			
Parameters	**Description**	**Indicators**	**References**
Socioeconomic strategies for workers	Avoidance of unsafe acts/conditions, promoting gender equality, labor rights, habitable living conditions, grievance redressal mechanism, sustainability awareness, training, skills, and others for workers during construction	Adopting a framework for defining and delivering socioeconomic benefits to the construction workforce *	[68,73–77]
Long term value to the society and local quality of life	Environmental practices at construction sites	Adopting guidelines for mitigation of air pollution, noise pollution, traffic, congestion, waste, and other pollution created on site and in surrounding areas	[68,78,79]

Table 2. *Cont.*

Social Sustainability Parameters (Phase 4. Operation and Maintenance)			
Parameters	**Description**	**Indicators**	**References**
Prioritizing occupant's comfort	Creating an environment that enhances occupant's comfort during operational phase	Adopting a framework for measuring and enhancing occupant's comfort *	[68,80–83]
Operations for protecting and improving health	Support and enhancement of physical/mental health, minimization of infectious disease transmission, accessibility to public transport, space for physical activities, healthy food options, access to clean water, and others	Conducting postoccupancy evaluation survey results and adopting mitigation measures for infectious disease and improving health in a built environment	[68,84–86]
Socioeconomic strategies during the operational phase	Creating wider social and economic benefits to relevant stakeholders	Adopting a framework for assessing and promoting diversity, equity, and inclusions among stakeholders	[68,87,88]
Social Sustainability Parameters (Phase 5. End of life)			
Parameters	**Description**	**Indicators**	**References**
Effective project communication	Disclosure/digital dissemination of information to the public about dismantling process, and other related issues	Evaluate the level of communication among stakeholders *	[89,90]
Security	Work and safety plan for the contaminated/noncontaminated area, and other related issues	Considerations of guidelines related to health, safety, and security of the stakeholders *	[90–92]

[1] * For further explanation refer to Appendix B.

Table 3. Pool of relevant economic based sustainability assessment parameters for different phases of construction.

Economic Sustainability Parameters (Phase 1. Conceptual Planning and Feasibility Study)			
Parameters	**Description**	**Indicators**	**References**
System of environmental–economic accounting	Integrating economic and environmental data for analysing the interrelationship between economy and environmental stock changes	Adopting/implementing framework for assessing the trends in the stocks of natural resources, emissions, and discharges in the environment resulting from economic activities; accounting of environmental preservation cost and conservation cost	[93,94]
Financial and economic feasibility	Estimating the return on investment, creditworthiness, viability, and cash flow during the entire life cycle of a project	Financial and economic feasibility assessment report of construction projects	[76,95,96]
Cost management plan	Concerning different processes and planning for controlling the cost of resources and other costs of the construction	Adopting framework to avoid time and cost overrun during different phases of a construction	[96–99]
Human resource planning	Concerning the capacities and capabilities of an individual worker in contributing towards sustainability	Adopting a framework for human resource management (HRM), focusing on aspects such as defined task domain of an employee, recruitment, remuneration, working conditions, training of the workforce, etc.	[100–104]

Table 3. *Cont.*

Economic Sustainability Parameters (Phase 1. Conceptual Planning and Feasibility Study)			
Parameters	**Description**	**Indicators**	**References**
Supply chain collaboration	Strategies for collaborative practices, ensuring selection of order winners for improved business case	Measuring level of collaboration in the supply chain, i.e., collaboration index	[105–110]
Targeted incentives	Strategies for incentivizing to increase worker's motivation and improving work productivity	Adopting a framework for targeted incentive schemes during different project phases	[111–113]
Ability to pay and affordability	Cost bearing ability of users during construction, operation, and maintenance of a project	Adopting framework to evaluate/facilitate the cost reduction of the constructed facility	[47,114]
Economic Sustainability Parameters (Phase 2. Design and Engineering)			
Parameters	**Description**	**Indicators**	**References**
Design for quality of service	Design with considerations and promoting resource efficiency by adopting principle shift from linearity to circularity in construction	Adopting design principles such as: functionality and usability, durability and reliability, design for maintenance consideration, flexibility and adaptability for future changes, design for assembly and disassembly (DfD), design for extended life, and reuse/remanufacturing/recycling, specifying reclaimed/recycled materials, and others	[6,23,115]
Life cycle costing for alternative designs	Estimate the costing of the entire life cycle of the construction project, which includes acquisition cost, facility management (operational) cost, and disposal cost	Adopting framework that assists in different design/specifications alternatives with different cash flows over life cycle of construction project	[70,116,117]
Economic Sustainability Parameters (Phase 3. Construction)			
Parameters	**Description**	**Indicators**	**References**
Cost, quality, and schedule management	Ensure reduction in the cost of poor quality work and avoid time–cost overruns in building/construction projects	Adopting a framework for performance management in construction projects	[118–122]
Innovation and productivity	Enhance growth through innovation and productivity in building/construction projects	Adopting a framework for promoting innovation and productivity in construction processes	[123–125]
Economic Sustainability Parameters (Phase 4. Operation and Maintenance)			
Parameters	**Description**	**Indicators**	**References**
Operational costs	Estimating operational and maintenance cost of built nvironment	Adopting models for predicting life cycle costing that includes the cost for periodic inspections, facility's operational cost, preventive maintenance cost, replacement and repairs cost, and reactive maintenance cost	[126–128]
Risk management and long term asset value	Ensure resilience of the built assets by managing risks proactively	Adopting a framework for built asset management with indicators such as responsible building operations, maintenance of built assets, managing environmental risks, analysing potential risks, and preparation for climate action	[128,129]

Table 3. *Cont.*

Economic Sustainability Parameters (Phase 4. Operation and Maintenance)			
Parameters	**Description**	**Indicators**	**References**
Sustainable operations and procurement	Ensure sustainable conscious operations and procurement with acknowledged social and environmental standards	Adopting guidelines for sustainable building operations, selecting suppliers and service providers, technical monitoring, maintenance, and construction measures	[128,130,131]
Economic Sustainability Parameters (Phase 5. End-of-life)			
Parameters	**Description**	**Indicators**	**References**
Risk assessment and cost security	To assess and mitigate the economic/financial risks associated with decommissioning of project	Adopting a framework for risk management, which includes: estimating cost of the dismantling process, assessing the uncertainties and financial risks with the estimates of dismantling cost	[90,132,133]
Values of expandable resources	Devise strategies for estimating the flow of building stocks	Maintaining account of building stocks that are potential expandable components *	[90,134]
Separation, recycling, and disposal	Prudent and circular use of materials and products	Adopting framework for circular use of C&D waste *	[90,135–137]
Tendering Process	Contract award based on parameters such as separate collection rate, sorting rate, recycling rate, hazardous substance plan, site equipment plan, and others	Adopting a conceptual framework for assessing the contractor's eligibility and performance	[90,138]

* For further explanation refer to Appendix B.

Table 4. Pool of relevant environmental based sustainability assessment parameters for different phases of construction.

Environmental Sustainability Parameters (Phase 1. Conceptual Planning and Feasibility Study)			
Parameters	**Description**	**Indicators**	**References**
System of environmental–economic accounting	Integrating economic and environmental data for analysing the interrelationship between economy and environmental stock changes	Adopting/implementing framework for assessing the trends in the stocks of natural resources, emissions, and discharges in the environment resulting from economic activities; accounting of environmental preservation cost and conservation cost	[93,94]
Environmental feasibility report/environmental impact assessment	Potentials benefits and ecological risks associated with the proposed project	Evaluating air, water, noise, land, and other pollution monitoring, prevention, and control strategies	[76,139–141]
Environmental management plan	Plan for controlling the environmental cost associated with the life cycle phases of a construction	Adopting a framework for environmental cost management accounting	[47,142]

Table 4. *Cont.*

Environmental Sustainability Parameters (Phase 2. Design and Engineering)			
Parameters	**Description**	**Indicators**	**References**
Design with safe, healthy, and circular building materials	Promoting the use of materials that can be salvaged and reused aimed at sustainable consumption and production	Adopting/implementing framework for assessing the trends in the stocks of natural resources, emissions, and discharges in the environment resulting from economic activities; accounting of environmental preservation cost and conservation cost	[37,68,70,143–145]
Design for harmony between nature and the built environment	Design with considerations such as access to nature, biophilic benefit to people, occupants' access to nature outdoors, and encouraging biodiversity within site footprints and surroundings	Adopting assessment framework for assessing the value of habitat that includes estimating the quantity and quality of biodiversity gained or lost, comparing pre- and postconstruction phases	[68,146–148]
Design for protecting and improving health	Design for maintaining/improving indoor air quality, water quality in order to minimize health risks	Adopting WHO Air Quality Guidelines, ASHRAE set benchmarks and WHO Guidelines for drinking water quality	[68,149–152]
Design for tackling climate change	Design with a commitment to water efficiency, net zero life cycle emissions, resilience against climate change and extreme weather events across all life cycle phases	Adopting guidelines for net zero emissions and climate resilience with design strategies aimed at mitigation and adaptation	[153,154]
Environmental Sustainability Parameters (Phase 3. Construction)			
Parameters	**Description**	**Indicators**	**References**
Water use efficiency and managing local shortage crisis	Commitment towards water reduction in material production and different construction phases	Adopting a strategic framework for adopting and promoting water saving across life cycle phases of a construction	[68,155–159]
Safe, healthy, and circular use of building materials	Avoid usage of hazardous building materials, promote recycling and circular use of building materials	Adopting monitoring framework towards material loop closing in construction processes with focus on: designing out the waste, using circular building products preferring refurbished, recycle, and remanufactured products	[160–164]
Environmental Sustainability Parameters (Phase 4. Operation and Maintenance)			
Parameters	**Description**	**Indicators**	**References**
Water use efficiency and managing local shortage crisis	Ensure commitment towards water demand reduction, wastewater treatment, rainwater management, and preserving water qualities for minimizing health risks	Adopting a strategic framework for promoting water saving across life cycle phases of a construction	[68,165–167]
Solid waste management	Ensure waste management systems are in place aimed at waste elimination, waste minimization, and material reuse	Adopting decision support framework for solid waste management postoccupancy	[68,70,168–170]
Air quality management	Ensure ambient air quality indoors and outdoors by real time monitoring	Adopting a framework for integrating air quality impacts in life cycle assessment	[68,171,172]

Table 4. *Cont.*

Environmental Sustainability Parameters (Phase 5. End of life)			
Parameters	**Description**	**Indicators**	**References**
Material flow balance	C&D waste generated during demolition/decommissioning phase	Adopting a framework for acounting of masses arising in demolition/dismantling process, maintaining inventory of massess incurred, estimationg the distance, and others	[90,173,174]
Life cycle assessment of material flows	Environmental impacts/risks because of output flows, waste generated, emissions, and others	Adopting a framework for estimating/preventinng environmental impact arising from demolition of the constructed facility	[90,175]
Hazardous substance remediation	Hazardous substances generated during demolition/decommissioning phase	Adopting hazardous substance remediation guidelines and accounting of hazardous substances separately	[90,176]

3.2. A Methodological Framework for Calculating TBL Scores and Decoupling Indices for Life Cycle Phases

Methodological frameworks provide the structure to guide users by using stages or a step by step approach. They help in improving the consistency, robustness, and reporting of the activity, the quality of the research, the standardization of approaches, and maximizing the trustworthiness of the results [177]. Figure 3 illustrates the proposed LCSA framework in six steps.

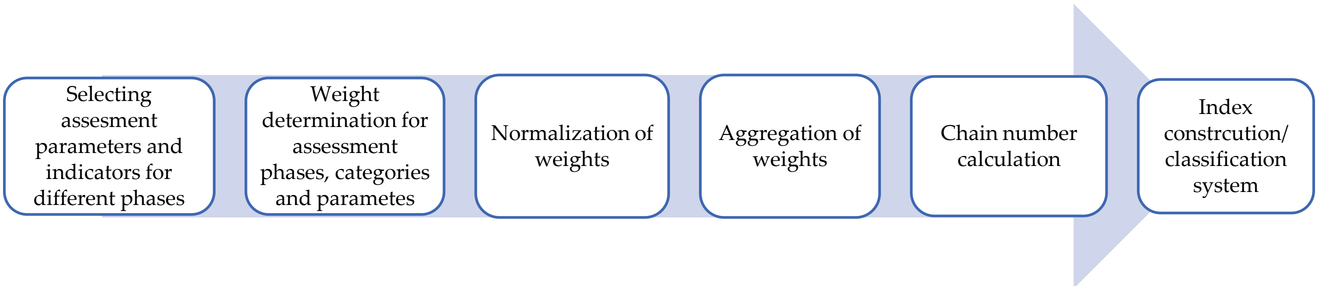

Figure 3. Steps for LCSA framework.

3.2.1. Identification of Potential Sustainability Parameters/Indicators for Life Cycle Phases of Construction and Weight Determination for Assessment Phases, Categories, and Parameters

Based on common consensus, the assessment parameters and corresponding indicators for construction phases are to be identified using suitable multicriteria decision analysis (MCDA) techniques. After finalizing assessment parameters and corresponding indicators (Tables 2–4), the weights that are to be allocated for project phases (W_k, k = 1 i.e., Conceptual Planning and Feasibility Study, k = 2 i.e., Design and Engineering, k = 3 i.e., Construction, k = 4 i.e., Operation and Maintenance, and k = 5 i.e., End of life), assessment categories (W_l, l = 1 i.e., social, l = 2 i.e., economic, l = 3 i.e., environment), and assessment parameters (W_m, m = 1 . . . . n, where n is a number of assessment parameters). Yu et al. (2018) [13] follow a similar approach in their study.

3.2.2. Benchmark/Baseline Score Matrix of Sustainability Assessment

Setting a benchmark score or target score under each of the sustainability assessment parameters (Table 1) is a key feature in most sustainability assessment rating tools/schemes.

A benchmark/baseline score is a product of the phase weight (W_k), category weight (W_l) and parameter weight (W_m) (Equation (2)).

$$Benchmark/Baseline\ score = Wk * Wl * \sum_{m=1}^{n} Wm \quad (2)$$

Similarly, Table 5 represents the benchmark or baseline score matrix. In simple words, each cell represents the maximum performance under the corresponding phase and sustainability pillar.

Table 5. Benchmark/baseline score matrix.

Project Phase → / Sustainability Pillars ↓	Conceptual Planning and Feasibility Study	Design and Engineering	Construction	Operation and Maintenance	End of Life	Life Cycle Benchmark TBL Score (LCBTS) ↓
Social	$W1*W1*\sum_{m=1}^{n} Wm$	$W2*W1*\sum_{m=1}^{n} Wm$	$W3*W1*\sum_{m=1}^{n} Wm$	$W4*W1*\sum_{m=1}^{n} Wm$	$W5*W1*\sum_{m=1}^{n} Wm$	$W1*\sum_{k=1}^{5}\sum_{m=1}^{n} Wk*Wm$
Economic	$W1*W2*\sum_{m=1}^{n} Wm$	$W2*W2*\sum_{m=1}^{n} Wm$	$W3*W2*\sum_{m=1}^{n} Wm$	$W4*W2*\sum_{m=1}^{n} Wm$	$W5*W2*\sum_{m=1}^{n} Wm$	$W2*\sum_{k=1}^{5}\sum_{m=1}^{n} Wk*Wm$
Environment	$W1*W3*\sum_{m=1}^{n} Wm$	$W2*W3*\sum_{m=1}^{n} Wm$	$W3*W3*\sum_{m=1}^{n} Wm$	$W4*W3*\sum_{m=1}^{n} Wm$	$W5*W3*\sum_{m=1}^{n} Wm$	$W3*\sum_{k=1}^{5}\sum_{m=1}^{n} Wk*Wm$
Project Phase Benchmark Sustainability Score (PPBSS) →	$W1*\sum_{l=1}^{3}\sum_{m=1}^{n} Wl*Wm$	$W2*\sum_{l=1}^{3}\sum_{m=1}^{n} Wl*Wm$	$W3*\sum_{l=1}^{3}\sum_{m=1}^{n} Wl*Wm$	$W4*\sum_{l=1}^{3}\sum_{m=1}^{n} Wl*Wm$	$W5*\sum_{l=1}^{3}\sum_{m=1}^{n} Wl*Wm$	$\sum_{K=1}^{5}\sum_{l=1}^{3}\sum_{m=1}^{n} Wk*Wl*Wm$ **Cumulative Benchmark Sustainability Score (CBSS)**

3.2.3. Computation of Normalized Performance Score Matrix of Sustainability Assessment

In sustainability assessment, the rationale underpinning the normalization of scores is to transform the measurement of different assessment parameters/indicators to a common unit, and to ease out the inclusion for aggregate sustainability assessment scores. For example, if the benchmark (maximum) score/credit points for an assessment category (social) is 24 and, during the assessment process, a project obtains 15 credit points out of 24 maximum available points, then the normalized social score is (15/24 = 0.625) (Equation (3)).

$$Normalized\ performance\ score\ (P_{nor}) = Performance\ assessment\ score/Performance\ benchmark\ score \quad (3)$$

where,

Performance assessment score is the score obtained by a project in a particular assessment parameter and Performance benchmark score (Equation (2)) is the maximum score that can be obtained in a particular assessment parameter. It may be noted that other approaches towards normalization can also be adopted and the present method has been used in the absence of more definitive and universally acceptable methodology.

Similarly, Table 6 represents the normalized performance score matrix; each cell represents performance under the corresponding phase and sustainability pillar.

Table 6. Normalized performance score matrix.

Project Phase → / Sustainability Pillars ↓	Conceptual Planning and Feasibility Study	Design and Engineering	Construction	Operation and Maintenance	End of Life	Life Cycle TBL Score (LCTS) ↓
Social	$\sum_{m=1}^{n} \text{P nor1, 1, m}$	$\sum_{m=1}^{n} \text{P nor2, 1, m}$	$\sum_{m=1}^{n} \text{P nor3, 1, m}$	$\sum_{m=1}^{n} \text{P nor4, 1, m}$	$\sum_{m=1}^{n} \text{P nor5, 1, m}$	$\sum_{k=1}^{5} \sum_{m=1}^{n} \text{P nork, 1, m}$
Economic	$\sum_{m=1}^{n} \text{P nor1, 2, m}$	$\sum_{m=1}^{n} \text{P nor2, 2, m}$	$\sum_{m=1}^{n} \text{P nor3, 2, m}$	$\sum_{m=1}^{n} \text{P nor4, 2, m}$	$\sum_{m=1}^{n} \text{P nor5, 2, m}$	$\sum_{k=1}^{5} \sum_{m=1}^{n} \text{P nork, 2, m}$
Environment	$\sum_{m=1}^{n} \text{P nor1, 3, m}$	$\sum_{m=1}^{n} \text{P nor2, 3, m}$	$\sum_{m=1}^{n} \text{P nor3, 3, m}$	$\sum_{m=1}^{n} \text{P nor4, 3, m}$	$\sum_{m=1}^{n} \text{P nor5, 3, m}$	$\sum_{k=1}^{5} \sum_{m=1}^{n} \text{P nork, 2, m}$
Project Phase Sustainability Score (PPSS) →	$\sum_{l=1}^{3} \sum_{m=1}^{n} \text{P nor1, l, m}$	$\sum_{l=1}^{3} \sum_{m=1}^{n} \text{P nor2, l, m}$	$\sum_{l=1}^{3} \sum_{m=1}^{n} \text{P nor2, l, m}$	$\sum_{l=1}^{3} \sum_{m=1}^{n} \text{P nor2, l, m}$	$\sum_{l=1}^{3} \sum_{m=1}^{n} \text{P nor2, l, m}$	$\sum_{K=1}^{5} \sum_{l=1}^{3} \sum_{m=1}^{n} \text{P nork, l, m}$ Cumulative Sustainability Score (CSS)

3.2.4. Chain Numbers of Performance Score Matrix of Sustainability Assessment

The chain number method is commonly employed in econometric analysis, in which value of any given period is related to its immediate predecessor value (values expressed as against preceding value = 100 or 1) [178]. Similarly, chain numbers for social well-being, environmental well-being, and environmental pressure (1-normalized environmental score) (Equation (4)) can be calculated by using a simple aggregative method, representing the sustainability performance of a particular phase of construction with respect to the preceding phase of construction. For example, in Table 9, Case-1, if the normalized social score in the preconstruction phase, as expressed, is 15/24 = 0.625 and the normalized social score in the construction phase, as expressed, is (14/24 = 0.583) then the chain index (SOPn) for the preconstruction and construction phases will be (0.625/0.625 = 1) and (0.583/0.625 = 0.93), respectively (Equation (5)).

$$\textit{Environmental pressure} = 1 - \textit{Normalized environment score} \tag{4}$$

$$\textit{Chain Index} = \textit{Normalized performance score of current phase/Normalized performance score of base phase} \tag{5}$$

3.2.5. Computation of Phase Well-Being Decoupling Index and Phase Impact Decoupling Index

Examining the importance of decoupling analysis in sustainability assessment and based on decoupling theory, this step involves the development of two decoupling indices, namely: (1) phase well-being decoupling index (2) phase impact decoupling index. The phase well-being decoupling index estimates if there is an increase in social well-being corresponding to the environmental pressure (1-normalized environmental score) for different phases (Equation (6)). The phase impact decoupling index estimates if there is an increase in economic performance corresponding to the environmental pressure (1-normalized environmental score) for different phases (Equation (7)).

$$\textit{Phase well-being decoupling index of stage K } (PWBDI_K) = SOPn/ENPn \tag{6}$$

$$\textit{Phase impact decoupling index of stage K } (PIDI_K) = ECPn/ENPn \tag{7}$$

where,

SOPn is the chain index of the normalized social performance score of one phase to the next phase;

ECPn is the chain index of the normalized economic performance score of one phase to the next phase;

ENPn is the chain index of the normalized environmental pressure score of one phase to the next phase;

$PWBDI_K$ is the ratio of the change in social well-being performance to the change in environmental pressure upon moving from one phase to the next phase;

$PIDI_K$ is the ratio of the change in social well-being performance to the change in environmental pressure upon moving from one phase to the next phase.

3.2.6. Classification System Based on TBL Scores and Decoupling Indices for Different Life Cycle Phases

Table 7 presents the description of the different cases of coupling and decoupling that are possible after computation of the phase well-being and impact decoupling indices. Li et al. (2019) [179] provide a similar kind of cut off values of decoupling degrees. Figure 4 is a graphical representation of the state of sustainability (ideal, permitted, and prohibited) that arise from different combinations of $PWBDI_K$ and $PIDI_K$, as given in Table 7.

Table 7. Description of different types of coupling/decoupling based on $PWBDI_K$ and $PIDI_K$.

Type of Coupling/Decoupling		Possible Cases	Remark	State of Sustainability
PWBDI k > 1	Absolute well-being decoupling	SOPn > 1, ENPn < 1	Increase in social well-being but decrease in environmental pressure	Ideal state
	Relative well-being decoupling	SOPn > 1, ENPn > 1	Increase in social well-being exceeds increase in environmental pressure	
	Contract well-being decoupling	SOPn < 1, ENPn < 1	Decrease in social well-being is less than the decrease in environmental pressure	Permitted state
PWBDI k < 1	Expansive well-being recoupling	SOPn > 1, ENPn > 1	An increase in social well-being is coupled with increasing environmental pressure	Prohibited state
	Absolute well-being recoupling	SOPn < 1, ENPn > 1	Decrease in social well-being with increase in environmental pressure	
	Relative well-being recoupling	SOPn < 1, ENPn < 1	Decrease in social well-being is more than the decrease in environmental pressure	
PIDI k > 1	Absolute impact decoupling	ECPn > 1, ENPn < 1	An increase in economic well-being but decrease in environmental pressure	Ideal state
	Relative impact decoupling	ECPn > 1, ENPn > 1	An increase in economic well-being exceeds increase in environmental pressure	
	Contract impact decoupling	ECPn < 1, ENPn < 1	Decrease in economic well-being is less than the decrease in environmental pressure	Permitted state
PIDI k < 1	Expansive impact recoupling	ECPn > 1, ENPn > 1	An increase in economic well-being is coupled with increasing environmental pressure	Prohibited state
	Absolute impact recoupling	ECPn < 1, ENPn > 1	Decrease in economic well-being with increase in environmental pressure	
	Relative impact recoupling	ECPn < 1, ENPn < 1	Decrease in economic well-being is less than the decrease in environmental pressure	

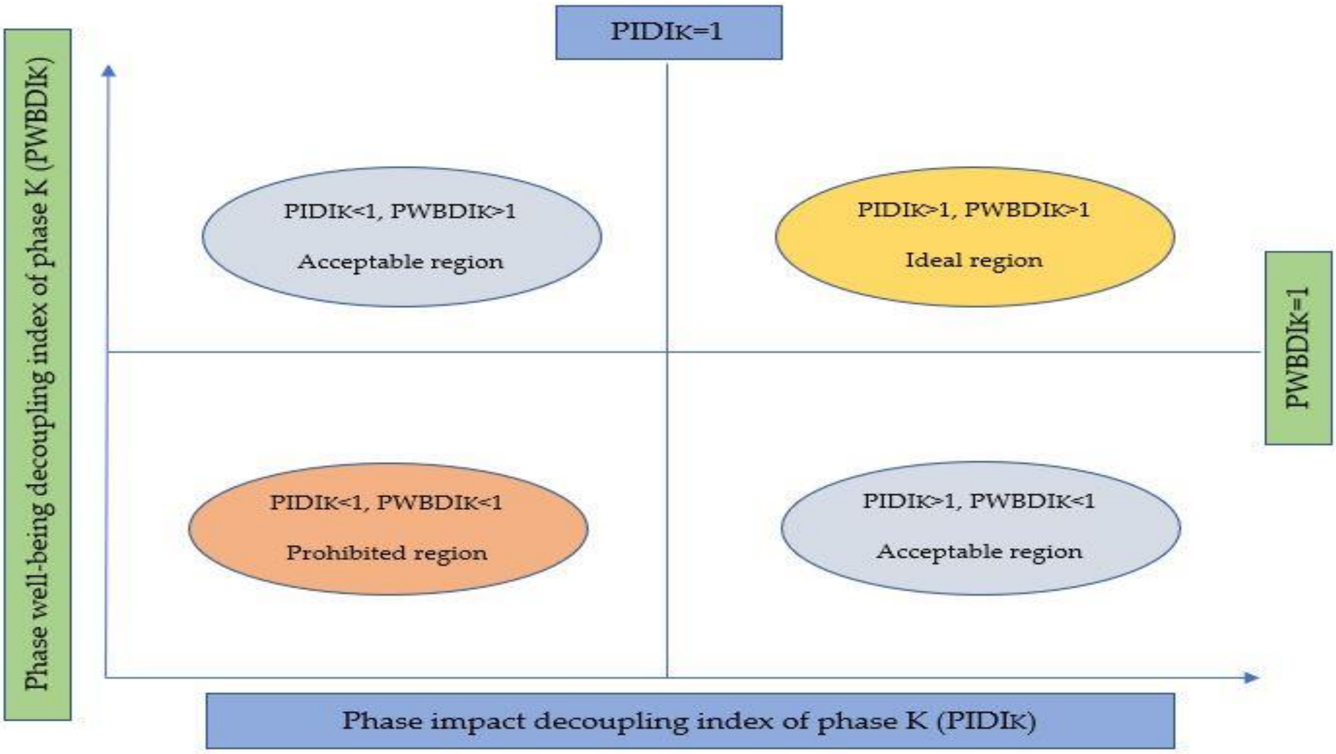

Figure 4. Categorization of states in sustainability based on phase well-being and phase impact decoupling indices.

4. Applicability of Proposed Methodological Framework

This section presents the details of applying a TBL based sustainability assessment criteria, as given in Table 8, for three hypothetical cases and the related computations for the phase well-being decoupling index ($PWBDI_K$) and phase impact decoupling index ($PIDI_K$), as given in Table 9. The criteria chosen in the present formulation are based on the GRIHA Precertification scheme and GRIHA v.2019, a justification for which is also included for completeness.

Table 8. Benchmark score and performance score matrix of the three cases.

Sustainability Assessment Parameters	Pre-Construction Phase				Construction Phase			
Assessment Criteria	Benchmark Score	Performance Score			Benchmark Score	Performance Score		
		Case-1	Case-2	Case-3		Case-1	Case-2	Case-3
So-1: Sustainable Site Planning—Green Infrastructure	3	2	3	3	3	2	3	2
So-2: Occupant Comfort—Visual Comfort	4	3	3	4	4	3	2	2
So-3: Occupant Comfort—Thermal and Acoustic Comfort	2	1	0	2	2	1	1	2
So-4: Occupant Comfort—Indoor Air Quality	6	4	2	5	6	4	3	3
So-5: Socio-Economic Strategies—Safety and Sanitation for Construction Workers	1	1	1	1	1	1	1	1
So-5: Socioeconomic Strategies—Universal Accessibility	2	1	1	2	2	1	1	2
So-6: Socioeconomic Strategies—Dedicated Facilities for Service Staff	2	1	1	2	2	1	1	2

Table 8. *Cont.*

So-7: Socioeconomic Strategies—Positive Social Impact	4	2	3	3	4	2	3	3
Ec-1: Life Cycle Costing—Life Cycle Costing Analysis	5	3	4	5	5	2	4	3
En-1: Sustainable Site Planning—Green Infrastructure	2	2	1	2	2	2	2	1
En-2: Sustainable Site Planning—Low-Impact Design Strategies	5	3	2	4	5	3	3	4
En-3: Sustainable Site Planning—Low-Impact Design Strategies	2	1	1	2	2	1	1	1
En-4: Construction Management—Air and Soil Pollution Control	1	1	1	1	1	1	0	1
En-5: Construction Management—Topsoil Preservation	1	0	1	1	1	1	0	1
En-6: Construction Management—Construction Management Practices	2	1	2	2	2	1	1	2
En-7: Energy Optimization—Energy Optimization	12	8	10	10	12	7	8	4
Energy Optimization—Renewable Energy Utilization	5	4	3	4	5	2	2	3
En-8: Energy Optimization—Low ODP and GWP Materials	1	0	0	1	1	0	1	1
En-9: Water Management—Water Demand Reduction	3	2	2	3	3	2	3	2
En-10: Water Management—Wastewater Treatment	3	1	2	3	3	2	2	2
En-11: Water Management—Rainwater Management	5	4	3	3	5	2	4	3
En-12: Water Management—Water Quality and Self-sufficiency	5	3	2	2	5	1	3	2
En-13: Solid Waste Management—Waste Management-Post Occupancy	4	4	3	3	4	3	4	4
En-14: Solid Waste Management—Organic Waste Treatment On-site	2	2	2	2	2	1	2	2
En-15: Sustainable Building Materials—Utilization of Alternative Materials in Building	5	3	4	4	5	3	4	3
En-16: Sustainable Building Materials—eduction in GWP through Life Cycle Assessment	5	3	2	3	5	3	2	3
En-17: Sustainable Building Materials—Alternative Materials for External Site Development	2	1	0	1	2	1	1	1
En-18: Performance Metering and Monitoring—Commissioning for Final Rating	0	0	0	0	0	0	0	0
En-19: Performance Metering and Monitoring—Smart Metering and Monitoring	6	4	3	5	6	4	4	4

Table 8. *Cont.*

En-20: Performance Metering and Monitoring—Operation and Maintenance Protocol	0	0	0	0	0	0	0	0

Table 9. Computation of phase well-being decoupling index and phase impact decoupling index for the three cases.

	Case-1		**Case-2**		**Case-3**	
	Pre-Construction Phase	**Construction Phase**	**Pre-Construction Phase**	**Construction Phase**	**Pre-Construction Phase**	**Construction Phase**
Social Score	15	14	22	15	15	17
Economic Score	3	4	5	2	4	3
Environment Score	47	44	56	38	47	44
Normalized Social Score	0.625	0.583	0.92	0.625	0.625	0.71
Chain Index (SOPn)	1.00	0.93	1.00	0.68	1.00	1.14
Normalized Economic Score	0.60	0.80	1.00	0.40	0.80	0.60
Chain Index (ECPn)	1.00	1.33	1.00	0.40	1.00	0.75
Normalized Environment Score	0.66	0.62	0.79	0.54	0.66	0.62
Normalized Environmen-tal Pressure Score	0.34	0.38	0.21	0.46	0.34	0.38
Chain Index (ENPn)	1.00	1.12	1.00	2.19	1.00	1.12
Cumulative Score	65	62	83	55	66	64
# GRIHA rating	***	***	****	**	***	***
Chain Number	1.00	0.95	1.00	0.66	1.00	0.64
PWBDI	0.83		0.31		1.02	
Remark	Decrease in social well-being with the increase in environmental pressure		Decrease in social well-being with the increase in environmental pressure		An increase in social well-being exceeds the increase in environmental pressure	
PIDI	1.19		0.18		0.67	
Remark	An increase in economic well-being exceeds the increase in environmental pressure		Decrease in economic well-being with the increase in environmental pressure		Decrease in economic well-being with the increase in environmental pressure	
Categorization	Acceptable region		Prohibited region		Acceptable region	

"*" in the different columns refers to the rating as per GRIHA. For example, "***" is three star which is given as "***".

Apart from the authors' regional context and understanding of the industry, some of the other important reasons for selecting the GRIHA's criteria for use in the proposed framework are explained in the following paragraphs:

1. According to the latest report of IPCC (2021) [180], we are already on a trajectory towards a 1.2 degrees Centigrade increase and we must act immediately to meet the 1.5 degrees Centigrade target, highlighting the urgency of this issue. The solutions are clear but the willingness to implement solutions is still lacking. These solutions should focus on long term outcomes and impacts, focusing on inclusive and green economies, prosperity, cleaner air, and better health.
2. At present, more than 50% of the population live in cities and this is expected to grow to 70% by 2050. The urban population of India (17.7% of the world's population) has been rising sharply over the past decades and is projected to reach 9.9 billion by 2050 [181]. Rapid urbanization aimed at economic growth in developing regions of the world (mostly in Africa, Latin America, and Asia) creates unprecedented challenges on environmental and socio-economic fronts. As stated by the GRIHA Council, "as

per international commitments, India plans to reduce its energy intensity by 33%–35% by 2030 [182]. Green building design, construction and operation will play a critical role as they are synonymous to both sustainable construction and assured high performance".
3. Further, the GRIHA Council also stated that, "GRIHA—with its commitment towards Intended Nationally Determined Contributions (INDCs) has been instrumental in recent years for good practices and innovative solution for enhancing resource efficiency in the building sector. GRIHA's large scale adoption will have enormous potential in addressing challenges". However, like any other assessment tools/schemes, GRIHA, too, has scope for improvement in its assessment framework (as discussed in Section 2.2.1). The endeavor to create large scale impact by proposing a new assessment framework with modifications in the existing assessment framework and mapping projects using well-being and impact decoupling indices (Figure 3) will be instrumental in progressing towards true sense of sustainability.
4. The GRIHA rating tool has separate schemes for assessing the sustainability performance of the preconstruction (planning, feasibility, design and engineering) and construction (new construction) phases. Though the assessment parameters are defined from a TBL perspective, the weights allocated to different dimensions are not transparent, and are not based on a clear logical set of parameters.
5. In addition, to test the proposed life cycle assessment framework incorporating TBL and decoupling indices (phase well-being and impact well-being), TBL based sustainability scores for at least two phases are required. As GRIHA allows the same projects to be rated against its Pre-certification and New-Construction schemes, providing the TBL based assessment scores for the same project in different life cycle phases. This presents a good opportunity for testing the proposed framework with slight modifications in the assessment scores obtained by the projects in their different life cycle phases.

The GRIHA Precertification scheme represents the sustainability assessment of preconstruction phase, i.e., conceptual planning and feasibility study and design and engineering, clubbed together. The GRIHA v.2019 scheme represents the sustainability assessment of the construction phase. The benchmark scores for the different assessment criteria (Table 8) in these schemes have been developed based on the analytical hierarchical process (AHP) (GRIHA v.2019 Abridged Manual, 2019) [70]. Table 8 also shows the assumed performance score for three hypothetical cases in the preconstruction and construction phases. As mentioned above, the computations using these assumed values for the different indices, as defined in Equations (6) and (7), have been shown in Table 9.

5. Conclusions

Construction assessment schemes and tools have been widely criticized for ignoring the life cycle assessment of social and economic dimensions in their sustainability frameworks. Moreover, decoupling and its assessment, which is acknowledged as a core of sustainability frameworks, is also not captured by any of these sustainability assessment tools/schemes. This study is an attempt to answer the above limitations of current sustainability assessment tools/schemes by developing a methodological framework for the life cycle sustainability assessment of construction, incorporating TBL and decoupling principles. The main conclusions/findings from this study can be summarized as follows:

1. Construction, especially in the developing world, still operates on take, make, waste (linear/coupled) systems. Life cycle sustainability assessment (LCSA) frameworks that ensure continued economic and social well-being, but with reduced environmental pressures, are missing, i.e., decoupled systems have a clear role to play.
2. Comparative analysis of GRIHA (India), LEED-IGBC (India), Green Star (Australia), BCA Green Mark (Singapore), DGNB (Germany), CASBEE (Japan), BREEAM (UK), Green Globes (Canada), BEAM Plus (Hong Kong), and GSAS (Gulf countries) from a TBL perspective shows that most of these assessment tools are biased towards

environmental sustainability evaluation and have allocated 69 percent of total credit points, on average. Although most of these assessment tools try to evaluate social sustainability by allocating 25 percent of the total credit points, on average, economic sustainability has been mostly neglected in the sustainability assessment.

3. Only the DGNB (Germany) system was observed to have a balance in their approach for allocating credit points across the three dimensions of sustainability. It allocated 30, 30, and 40 percent of total credit points towards evaluating social, economic, and environmental dimensions of sustainability, respectively (Table 1). However, irrespective of initial weights across TBL dimensions, these rating tools provide classification systems based on an aggregate scoring system (except CASBEE) and, therefore, they lack in evaluating interactions among different pillars of sustainability.
4. Credit criteria, such as: ethical considerations, a system of environmental–economic accounting, targeted incentives, long term value to the society, design for harmony with nature and the built environment, and design for tackling climate change, are some of the key criteria that are not explicitly included in rating tools/schemes but are found in the literature. For optimized sustainability evaluation, these criteria should be included in the current sustainability rating tools/schemes (Tables 2–4).
5. DGNB (Germany) is the only rating tool that has a sustainability assessment scheme for rating the decommissioning/deconstruction phase of a building project (pilot mode). Considering the importance of the decommissioning phase in the building life cycle, TBL based sustainability assessment criteria for the decommissioning phase needs to be considered. Green building councils (GBCs) should focus on developing assessment schemes/tools and respective criteria for the decommissioning phase, taking account of the regional context.
6. The current study proposes a methodological framework for calculating life cycle based TBL scores and decoupling indices. Two decoupling indices are proposed, i.e., phase well-being decoupling index ($PWBDI_K$) (Equation (6) and phase impact decoupling index ($PIDI_K$) (Equation (7), for supporting TBL-based life cycle assessment. These developed decoupling indices specifically estimate the interdependence of human well-being, economic growth, and environmental pressure associated with construction projects. Construction projects in their different life cycle phases can be mapped using computed $PWBDI_K$ and $PIDI_K$ by referring to Table 7 and Figure 4 of this study.
7. The sustainability assessment criteria from the GRIHA Precertification and GRIHA v.2019 schemes, representing assessment criteria of pre-construction and construction phase, respectively, were used to illustrate the calculations in the proposed LCSA framework. For three hypothetical cases, $PWBDI_K$ and $PIDI_K$ were computed representing projects moving from the preconstruction phase to the construction phase. It was highlighted that for case-1 and case-3, their GRIHA rating (***) was maintained after sustainability evaluation of the preconstruction and construction phases. It can be seen from Tables 8 and 9 that the performance of case-2 changed from (****) to (**) when moving from the preconstruction phase to the construction phase. This can be taken to be an example of how the proposed framework can be used to ensure that projects do not lose track when moving from one phase to another.
8. The PWBDI value for case-1 indicates that there is a decrease in social well-being with an increase in environmental pressure, and the PIDI value for case-1 indicates that there is an increase in economic well-being that exceeds the increase in environmental pressure. The PWBDI value for case-2 indicates that there is a decrease in social well-being with an increase in environmental pressure and the PIDI value for case-2 indicates that there is a decrease in economic well-being with an increase in environmental pressure. The PWBDI value for case-3 indicates that there is an increase in social well-being that exceeds the increase in environmental pressure and the PIDI value for case-3 indicates that there is a decrease in economic well-being with an increase in environmental pressure (Tables 7 and 9). However, based on aggregate

scores, different scenarios are possible and, moreover, when these projects move from one phase to another phase, they can behave differently, irrespective of their base phase performance, as illustrated by the PWBDI and PIDI for GRIHA cases. For a better understanding of the proposed PWBDI/PIDI approach an illustrative example has been included in Appendix C.

The proposed methodological framework not only encapsulates a TBL based life cycle sustainability approach in construction, but also ensures a monitoring mechanism for the same using decoupling indices. Given the fact that the parameters involved in the operation and decommissioning phases could be quite different from those in the preconstruction and construction phases (as illustrated in Tables 2–4), the present study is confined to the preconstruction and construction phases only. It is agreed that scores derived from a "real" project would be more valuable and convincing. However, in the absence of such (real) data, the present study only presents the methodological framework and includes a "proof of concept" verification or validation on the basis of assumed (but "reasonable") values. The authors continue to strive to collect/access real data in their future works.

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Appendix A

Methodology for Detailed Division of Credits from TBL Consideration in Different Rating Tools/Schemes

Ten well-established rating tools/schemes representing different regions of the world for studying their approach to the TBL concept of sustainability were selected, namely, GRIHA (India), LEED-IGBC (India), Green Star (Australia), BCA Green Mark (Singapore), DGNB (Germany), CASBEE (Japan), BREEAM (UK), Green Globes (Canada), GBI (Malaysia), GSAS (Gulf countries). There are different types of schemes developed by these rating agencies to rate different typologies of construction projects. Keeping in mind the criticality and scale of adoption, only schemes that certify non-residential (new-constructions) under these rating agencies were chosen for critical evaluation in this study. And, a comparison based on weights of TBL (social, economic, and environment) among these tools is presented Table 1 of the manuscript.

The following text outlines the method adopted in this study for evaluating a comprehensive performance of projects on the basis of scores obtained on the social, economic, and environmental fronts.

1. The classification of the credit points for an individual parameter into social, economic, or environmental dimension was carried out using a subjective judgement based on available literature. This has been explained in Section 2.2.1 and Tables 2–4. of the manuscript. The user/technical manuals for each of these mentioned schemes were also referred.
2. However, in cases when a parameters/indicator was judged to belong to more than one dimension, the credits assigned to that particular category were divided equally

between/among the different dimensions of sustainability the parameter contributes. For example, in the DGNB classification system, under the category of Technical Quality, "Ease of cleaning building components" is one of the assessment parameters. Where the detailed description for this parameter at Criteria "Ease of cleaning building components" | DGNB System (dgnb-system.de), says *"The issue of how a building structure can be cleaned has a significant effect on the costs and environmental impact of a building during its use. Surfaces that can be easily cleaned require less cleaning agents and result in lower cleaning costs"*. Now, this parameter was qualitatively judged to belong to both—the economic and environmental heads, and therefore the allocated credit (1.66) for this parameter was equally assigned to the economic and environmental heads (i.e., it was taken to be 0.83 and 0.83 for further computations in both these heads).

3. In the case of DGNB (Germany), which declares a total of six categories – environment, economic, socio-culture, technical quality, process quality, and site quality. The document also mentions the respective parameters under each of these categories. Now, for the purpose of the present study, whereas the parameters for the first three were adopted as such, the parameters for the latter three were assigned to the former three using qualitative judgement.
4. Some of the assessment parameters/indicators under these rating tools/schemes are given as prerequisite. For example, In Part 3—"Resource Stewardship" of Green Mark (Singapore), water efficient fittings are listed as a prerequisite. The schemes expect compliance with respect to these as a minimum, and do not award any points for that in their scoring scheme. This approach has been adopted in the present study also and such parameters have been excluded from award of any credit points under these schemes.

GRIHA v.2019 Abridged Manual.

GRIHA	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Sustainable Site Planning-12%				
Criterion 1: Green Infrastructure	5	2 + 1 *		2
Criterion 2: Low-Impact Design Strategies	5			5
Criterion 3: Design to Mitigate UHIE	2			2
Construction Management-4%				
Criterion 4: Air and Soil Pollution Control	1			1
Criterion 5: Topsoil Preservation	1			1
Criterion 6: Construction Management Practices	2			2
Energy Optimization-18%				
Criterion 7: Energy Optimization	12			12
Criterion 8: Renewable Energy Utilization	5			5
Criterion 9: Low ODP and GWP Materials	1			1
Occupant Comfort-12%				
Criterion 10: Visual Comfort	4	4		
Criterion 11: Thermal and Acoustic Comfort	2	2		
Criterion 12: Indoor Air Quality	6	6		
Water Management-16%				
Criterion 13: Water Demand Reduction	3			3
Criterion 14: Wastewater Treatment	3			3
Criterion 15: Rainwater Management	5			5

GRIHA	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Criterion 16: Water Quality and Self-sufficiency	5			5
Solid Waste Management-6%				
Waste Management-Post Occupancy	4			4
Organic Waste Treatment On-site	2			2
Sustainable Building Mateials-12%				
Criterion 19: Utilization of Alternative Materials in Building	5			5
Criterion 20: Reduction in GWP through Life Cycle Assessment	5			5
Criterion 21: Alternative Materials for External Site Development	2			2
Life Cycle Costing-5%				
Life Cycle Costing Analysis	5		5	
Socio-Economic Strategies-8%				
Criterion 23: Safety and Sanitation for Construction Workers	1	1		
Criterion 24: Universal Accessibility	2	2		
Criterion 25: Dedicated Facilities for Service Staff	2	2		
Criterion 26: Positive Social Impact	4	4		
Performance Metering and Monitoring-7%				
Criterion 27: Commissioning for Final Rating	0			0
Criterion 28: Smart Metering and Monitoring	6			6
Criterion 29: Operation and Maintenance Protocol	0			0
Total	100			
Innovation				
Criterion 30: Innovation	5			
Grand Total		100 + 5 = 105		

Percentile thresholds for achieving stars in GRIHA v.2019.

Percentile Threshold	Achievable Stars as per GRIHA v. 2019
25–40	*
41–55	**
56–70	***
71–85	****
86 and more	*****

IGBC Green New Buildings Rating System.

IGBC	Maximum Points		Dimension of Sustainability		
	Owner-occupied Buildings	Tenant Occupied Buildings	Social	Economic	Environment
Sustainable Architecture and Design	5				
Integrated Design Approach	1	1	1		
Site Preservation	2	2			2
Passive Architecture	2	2			2
Site Selection and Planning	14				

IGBC	Maximum Points		Dimension of Sustainability		
	Owner-occupied Buildings	Tenant Occupied Buildings	Social	Economic	Environment
Local Building Regulations	Required	Required			
Soil Erosion Control	Required	Required			
Basic Amenities	1	1	1		*
Proximity to Public Transport	1	1	1		
Low-emitting Vehicles	1	1			1
Natural Topography or Vegetation	2	2			2
Preservation or Transplantation of Trees	1	1			1
Heat Island Reduction, Non-roof	2	2			2
Heat Island Reduction, Roof	2	2			2
Outdoor Light Pollution Reduction	1	1			1
Universal Design	1	1	1		
Basic Facilities for Construction Workforce	1	1	1		
Green Building Guidelines	1	1	1		1
Water Conservation	18				
Rainwater Harvesting, Roof & Non-roof	Required	Required			
Water Efficient Plumbing Fixtures	Required	Required			
Landscape Design	2	2			2
Management of Irrigation Systems	1	1			1
Rainwater Harvesting, Roof & Non-roof	4	4			4
Water Efficient Plumbing Fixtures	5	5			5
Wastewater Treatment and Reuse	5	5			5
Water Metering	1	2			1
Energy Efficiency	28				
Ozone Depleting Substances	Required	Required			
Minimum Energy Efficiency	Required	Required			
Commissioning Plan for Building Required Equipment & Systems	Required	Required			
Eco-friendly Refrigerants	1	1			1
Enhanced Energy Efficiency	15	15			15
On-site Renewable Energy	6	6			6
Off-site Renewable Energy	2	2			2
Commissioning, Post-installation of Equipment & Systems	2	2			2
Energy Metering and Management	2	2			2
Building Materials and Resources	16				
Segregation of Waste, Post-occupancy	Required	Required			
Sustainable Building Materials	8	8(1 + 2 + 2 + 2 + 2)		*	
Organic Waste Management, Post-occupancy	2	2			2
Handling of Waste Materials, During Construction	1	1			1

IGBC	Maximum Points		Dimension of Sustainability		
	Owner-occupied Buildings	Tenant Occupied Buildings	Social	Economic	Environment
Use of Certified Green Building Materials, Products & Equipment	5	5			5
Indoor Environmental Quality	12				
Minimum Fresh Air Ventilation	Required	Required			
Tobacco Smoke Control	Required	Required			
CO2 Monitoring	1	1	1		
Daylighting	2	2	2		
Outdoor Views	1	1	1		
Minimize Indoor and Outdoor Pollutants	1	1	1		
Low-emitting materials	3	3	3		
Occupant Well-being Facilities	1				
Indoor Air Quality Testing, After Construction and Before Occupancy	2	2	2		
Indoor Air Quality Management, During Construction	1	1	1		
Innovation and Development	7				
Innovation in Design Process	4	4			
Optimization in Structural Design	1	1			1
Waste Water Reuse, During Construction	1	1			1
IGBC Accredited Professional	1	1	1		
Total		100			

Percentile thresholds for different certification levels in IGBC Green New Buildings Rating System.

Certification Level	Owner-Occupied Buildings	Tenant-Occupied Buildings	Recognition
Certified	40–49	40–49	Best Practices
Silver	50–59	50–59	Outstanding Performance
Gold	60–74	60–74	National Excellence
Platinum	75–100	75–100	Global Leadership

Green Star—Design & As-Built, 2017.

Green Star	Maximum Points	Dimension of Sustainability		
	Owner-Occupied Buildings	Social	Economic	Environment
MANAGEMENT	14			
Green Star Accredited Professional	1	1		
Commissioning and Tuning	4	4		
Adaptation and Resilience	2			2
Building Information	1	1		
Commitment to Performance	2			2
Metering and Monitoring	1			1
Responsible Construction Practices	2	1		1
Operational Waste	1			1
INDOOR ENVIRONMENT QUALITY	17			
Indoor Air Quality	4	4		

Green Star	Maximum Points	Dimension of Sustainability		
	Owner-Occupied Buildings	Social	Economic	Environment
Acoustic Comfort	3	3		
Lighting Comfort	3	3		
Visual Comfort	3	3		
Thermal Comfort	2	2		
Access to Fresh Food	2	2		
ENERGY	22			
Greenhouse Gas Emissions	20			20
Peak Electricity Demand Reduction	2			2
TRANSPORT	10			
Sustainable Transport	10	5		5
WATER	12			
Potable Water	12			12
MATERIALS	14			
Life Cycle Impacts	7			7
Responsible Building Materials	3			3
Sustainable Product	3			3
Construction and Demolition Waste	1			1
LAND USE & ECOLOGY	6			
Ecological Value	3			3
Sustainable Sites	2			2
Heat Island Effect	1			1
EMISSIONS	5			
Stormwater	2			2
Light Pollution	1			1
Microbial Control	1			1
Refrigerant Impacts	1			1
Total	100			
INNOVATION	10			
Innovation	10	5		5
Grand Total		110		

Percentile thresholds for different certification levels in Green Star—Design & As-Built, 2017.

Percentage of Available Points	Rating	Outcome
<10	No *	Assessed
10–19	*	Minimum practice
20–29	**	Average practice
30–44	***	Good practice
45–59	****	Australian best practice
60–74	*****	Australian excellence
75+	******	World leadership

Green Mark for Non-Residential Building NRB:2015.

Green Mark	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Elective Requirements				
Part 1-Climate Responsive Design				
Climate Responsive Design	Prerequisite			
Envelope and Roof Thermal Transfer	Prerequisite			
Air Tightness and Leakage	Prerequisite			
Bicycle Parking	Prerequisite			
1.1 Leadership	10			
1.1a Climatic & Contextually Responsive Brief	1			1
1.1b Integrative Design Process (*4D, 5D & 6D BIM (Advanced Green Efforts))	4(*3)	*1	*1	*2
1.1c Environmental Credentials of Project Team	2	2		
1.1d User Engagement	3	3		
1.2 Urban Harmony	10 points			
1.2a Sustainable Urbanism	Up to 5 points			
(i) Environmental Analysis (* Creation of possible new ecology and natural ecosystems (Advanced Green Efforts))	2(*1)			2(*1)
(ii) Response to Site Context	3	1	1	1
(iii) Urban Heat Island (UHI) Mitigation	1			1
(iv) Green Transport	1.5	1.5		
1.2b Integrated Landscape and Waterscape	Up to 5 points			
Green Plot (i) Ratio (GnPR) (*GnPR ≥ 5.0 (Advanced Green Efforts))	3(*1)			3(*1)
(ii) Tree Conservation	1			1
(iii) Sustainable Landscape Management	1.5			1.5
(iv) Sustainable Storm Water Management	1			1
1.3 Tropical	10 points			
1.3a Tropical Façade Performance Low heat gain façade (Advanced Green Efforts) Greenery on the East and West Façade (Advanced Green Efforts) Thermal Bridging (Advanced Green Efforts)	3(*1, 1,1)	3(*1, 1,1)		
1.3b Internal Spatial Organisation	3	3		
1.3c Ventilation Performance (*Wind Driven Rain Simulation (Advanced Green Efforts))	4(*1)	4(*1)		
Part 2-Building Energy Performance	22 points			
Air Conditioning Total System and Component Efficiency	Prerequisite			
Lighting Efficiency and Controls	Prerequisite			
Vertical Transportation Efficiency	Prerequisite			
2.1 Energy Efficiency				
Option 1: Energy Performance Points Calculator				
2.1a Air Conditioning Total System Efficiency	5			5
2.1b Lighting System Efficiency	3			3
2.1c Carpark System Efficiency	2			2
2.1d Receptacle Efficiency	1			1
2.1e Building Energy (*Further Improvement in Design Energy Consumption (Advanced Green Efforts)	11(*2)			11(*2)
Option 2: Performance-Based Computation				
2.1f Space Conditioning Performance (*Efficient space conditioning energy design (Advanced Green Efforts))	10(*1)			10(*1)

Green Mark	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
2.1g Lighting Performance (*Efficient lighting design (Advanced Green Efforts))	6(*1)			6(*1)
2.1h Building System Performance (*Additional Energy-Efficient Practices and Features (Advanced Green Efforts))	6(*2)			6(*2)
2.2 Renewable Energy	8 points			
2.2a Solar Energy Feasibility Study	0.5			0.5
2.2b Solar Ready Roof	1.5			1.5
2.2c Adoption of Renewable Energy (*Further Electricity Replacement by Renewables (Advanced Green Efforts))	6(*5)			6(*5)
Part 3-Resource Stewardship				
Water Efficient Fittings	Prerequisite			
3.1 Water	8 points			
3.1a Water Efficient Systems	3			3
(i) Landscape irrigation	1			1
(ii) Water Consumption of Cooling Towers (*Better Water Efficient Fittings (Advanced Green Efforts)	2			2
3.1b Water Monitoring	2			2
(i) Water Monitoring and Leak Detection	1			1
(ii) Water Usage Portal and Dashboard	1			1
3.1c Alternative Water Sources	3			3
3.2 Materials	18 points			
3.2a Sustainable Construction	8			8
(i) Conservation and Resource Recovery	1			1
(ii) Resource Efficient Building Design (* Use of BIM to calculate CUI (Advanced Green Efforts))	4(*1)			4(*1)
(iii) Low Carbon Concrete (*Use of Advanced Green Materials (Advanced Green Efforts))	3(*1)			3(*1)
3.2b Embodied Carbon (*Provide Own Emission Factors with Source Justification (Advanced Green Efforts), Compute the Carbon Footprint of the Entire Development (Advanced Green Efforts))	2(*1,1)			2(*1,1)
3.2c Sustainable Products	8 points			
(i) Functional System	8			8
(ii) Singular Sustainable Products outside of Functional Systems (*Sustainable Products with Higher Environmental Credentials (Advanced Green Efforts))	2(*2)			2(*2)
3.3 Waste	4 points			
3.3a Environmental Construction Management Plan	1			1
3.3b Operational Waste Management	3			3
Part 4-Smart & Healthy Building				
Thermal Comfort	Prerequisite			
Minimum Ventilation Rate	Prerequisite			
Filtration Media for Times of Pollution	Prerequisite			
Low Volatile Organic Compound (VOC) Paints	Prerequisite			
Refrigerants	Prerequisite			
Sound Level	Prerequisite			
Permanent Instrumentation for the Measurement and Verification of Chilled Water Air-Conditioning Systems				
Electrical Sub-Metering & Monitoring	Prerequisite			

Green Mark	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
4.1 Indoor Air Quality	10 points			
4.1a Occupant Comfort	2	2		
(i) Indoor Air Quality (IAQ) Surveillance Audit	1	1		
(ii) Post Occupancy Evaluation	0.5	0.5		
(iii) Indoor Air Quality Display (* Indoor Air Quality Trending (Advanced Green Efforts)	0.5	0.5		
4.1b Outdoor Air	3 points	3 points		
(i) Ventilation Rates	1.5	1.5		
(ii) Enhanced Filtration Media	1	1		
(iii) Dedicated Outdoor Air System	0.5	0.5		
4.1c Indoor Contaminants	5 points	5 points		
(i) Local Exhaust and Air Purging System	2	2		
(ii) Ultraviolet Germicidal Irradiation (UVGI) System	0.5	0.5		
(iii) More Stringent VOC Limits for Interior Fittings and Finishes	2	2		
(iv)Use of Persistent Bio-cumulative and Toxic (PBT) free lighting (*Zero ODP Refrigerants with Low Global Warming Potential (Advanced Green Efforts))	0.5(*1)	0.5(*1)		
4.2 Spatial Quality	10 points	10 points		
4.2a Lighting	Up to 6 points	Up to 6 points		
(i) Effective daylighting for common areas	2	2		
(ii) Effective daylighting for occupied spaces	4	4		
(iii) Quality of Artificial Lighting	1	1		
4.2b Acoustics	2	2		
(i) Sound Transmission Reduction	0.5	0.5		
(ii)Acoustic Report	1.5	1.5		
4.2c Wellbeing	Up to 2 points	Up to 2 points		
(i) Biophilic Design	3			3
(ii) Universal Design (UD) Mark	1	1		
4.3 Smart Building Operations	10 points			
4.3a Energy Monitoring	3			3
(i) Energy Portal and Dashboard	2			2
(ii) BAS and Controllers with Open Protocol (* Permanent M&V for VRF Systems (Advanced Green Effort), Permanent M&V for Hot Water systems (Advanced Green Efforts))	1(*2,1)			1(*2,1)
4.3b Demand Control	3		3	
(i) ACMV Demand Control	2		2	
(ii) Lighting Demand Control	1		1	
(iii) Carpark Guidance System	0.5	0.5		
4.3c Integration and Analytics	3			
(i) Basic Integration and Analytics	0.5/feature			0.5/feature
(ii) Advanced Integration and Analytics (* Additional Advanced Integration and Analytical Features (Advanced Green Effort))	1/feature (*1)			1/feature (*1)
4.3d System Handover and Documentation	1	1		
Expanded Post Occupancy Performance Verification by a 3rd Party (Advanced Green Effort)	2	2		
Energy Performance Contracting (Advanced Green Effort)	1			1
Part 5-Advanced Green Efforts	20 points			
5.1 Enhanced Performance	Up to 15 points			15

Green Mark	Maximum Points	Dimension of Sustainability		
		Social	**Economic**	**Environment**
5.2 Complementary Certifications	1			1
5.3 Demonstrating Cost Effective Design	1		1	
5.4 Social Benefits	2	2		
Annexes for specialized buildings	10 to 15 points			
Annex 1: Energy Efficiency Features for Specialised Building [Hawker Centres]	15			15
Annex 2: Energy Efficiency Features for Specialised Building Healthcare Facilities]	10			10
Annex 3: Energy Efficiency Features for Specialised Building [Laboratories]	10			10
Annex 4: Energy Efficiency Features for Specialised Building [Schools]	10			10
Total		150–155		

Percentile thresholds for different certification levels in IGBC Green New Buildings Rating System.

Green Mark Rating	Green Mark Score (Percentage Point Scored)
Green Mark Platinum	70 and above
Green Mark Gold PLUS	60 to <70
Green Mark Gold	>50 to <60
Green Mark Certified	Compliance with all pre-requisite requirement

DGNB System criteria set-New Construction Building.

DGNB	Maximum Points	Dimension of Sustainability		
		Social	**Economic**	**Environment**
Environmental Quality	22.50%			
Building life cycle assessment				9.5
Local environmental impact				4.7
sustainable resource extraction				2.4
Potable water demand and wastewater volume				2.4
Land use				2.4
Bio-diversity at site				1.2
Economic Quality	22.50%			
Life cycle costing			10	
Flexibility and adaptability			7.5	
Commercial viability			5.0	
Socio-Cultural and functional quality	22.50%			
Thermal comfort		4.1		
Indoor air quality		5.1		
Acoustic comfort		2.0		
Visual comfort		3.1		
User control		2.0		
Quality of indoor and outdoor spaces		2.0		
Safety and security		1.0		
Design for all		3.1		
Technical Quality	15%			
Sound insulation		1.15		

DGNB	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Quality of the building envelope				2.96
Use and integration of building technology			1.23	1.23
Ease of cleaning building components			0.83	0.83
Ease of recovery and recycling			1.63	1.63
Emissions control		0.71		0.71
Mobility infrastructure		0.82	0.82	0.82
Process Quality	12.50%			
Comprehensive project brief		1.6		
Sustainability aspects in the tender phase				1.6
Documentation for sustainable management			1.1	
Procedure for urban and design planning		0.8		0.8
Construction site/construction process		0.8		0.8
Quality assurance of the construction		0.53	0.53	0.53
Systematic commissioning				1.6
User communication		0.55		0.55
FM-compliant planning				0.5
Site Quality	5%			
Local environment		0.55		0.55
Influence on the district			1.1	
Transport access		0.36	0.36	0.36
Access to amenities		0.85		0.85
Total		100%		

Classification of different certification levels as per DGNB System criteria set-New Construction Building.

Certification	Percentage Points
DGNB Platinum	65–80
DGNB Gold	50–65
DGNB Silver	35–50
DGNB Bronze	>35

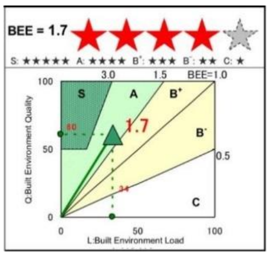
CASBEE.

CASBEE	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Water Efficiency	15			
Water leakage Detection	3.6			3.6
Water use during construction	1.8			1.8
Waste water management	7.2			7.2
Sanitary used pipe	2.4			2.4
Materials Resources	10			
Regionally procured materials	1.5	0.75	0.75	
Materials fabricated on site	0.5			0.5
Use of readily renewable materials	1.5			1.5

CASBEE	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Use of salvaged material	1.5		0.75	0.75
Use of recycled material	2		1.0	1.0
Use of lightweight materials	0.5			0.5
Use of higher durability materials	0.5			0.5
Use of prefabricated elements	1.5		0.75	0.75
Life cycle cost analysis of materials in the project	0.5		0.5	
Indoor Environmental Quality	10	10		
Sustainable Site, Accessibility and Ecology	15	7.5		7.5
Desert Area Development	1.5			1.5
Informal Area Development	1.5	1.5		
Brownfield site development	1.5			1.5
Compatibility with the national development plan	1.5			
Transport infrastructure connection	1.5	1.5		
Catering for remote site	1.5	1.5		
Alternative methods of transport	1.5			1.5
Protection of habitat	1.5			1.5
Energy Efficiency	25			
Passive External Heat Gain Loss	7.5			7.5
Reduction	3.5			3.5
Energy Efficient Appliances	1.5			1.5
Vertical Transportation Systems	1.5			1.5
Peak Load Reductions	3		1.5	1.5
Renewable Energy Sources	5			5
Environmental Impact	2			2
Energy and Carbon Inventories	1			1
Management	10			
Providing Containers for site materials waste	1			1
Control of emissions and pollutants	1			1
Waste recycling workers on site	0.5			0.5
Providing Identified and separated storage areas	1			1
Project Waste Management Plan	0.5			0.5
Engaging a company specialized in recycling	1	1		
Protecting water sources from pollution	1			1
Waste from mixing equipment	1			1
Total	85			

Classification of different certification levels as per CASBEE.

Ranks	Valuation	BEE Value	Indication
S	Excellent	BEE = 3.0 or more and Q = 50 or more	*****
A	Very Good	BEE = 1.5–3.0 BEE = 3.0 or more and Q is less than 50	****
B^+	Good	BEE = 1.0–1.5	***
B^-	Fairly Poor	BEE = 0.5–1.5	**
C	Poor	BEE is less than 0.5	*



BREEAM International New Construction 2016.

BREEAM	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Management	20			
Project brief and design	(2 + 2)	4		
Life cycle cost and service life planning	(2 + 1 + 1)		4	
Responsible construction practices	(1 + 1 + 2 + 2)	3		3
Commissioning and handover	(1 + 1 + 1 + 1)	*	4	
Aftercare	(1 + 1 + 1)	2		1 *
Health and wellbeing	22			
Visual comfort	6	6		
Indoor air quality	5	5		
Safe containment in laboratories	2	1		1
Thermal comfort	3	3		
Acoustic performance	4	4		
Accessibility	2	2		
Hazards	1	0.5	0.5	
Private space	1	1		
Water quality	1	1		*
Energy	35			
Reduction of energy use and carbon emissions	15			15
Energy monitoring	2			2
External lighting	1			1
Low carbon design	3			3
Energy-efficient cold storage	3			3
Energy-efficient transport systems	3			3
Energy-efficient laboratory systems	5			5
Energy-efficient equipment	2			2
Drying space	1			1
Transport	13			
Public transport accessibility	5	1.67	1.67	1.67
Proximity to amenities	2	0.67	0.67	0.67
Alternative modes of transport	2			2
Maximum car parking capacity	2			2
Travel plan	1	0.33	0.33	0.33
Home office	1	0.33	0.33	0.33
Water	10			
Water consumption	5		*	5
Water monitoring	1		*	1
Water leak detection	3		*	3
Water-efficient equipment	1		*	1
Materials	12			
Life cycle impacts	6			6
Hard landscaping and boundary protection	N/A			
Responsible sourcing of materials	4	*	*	4
Insulation	N/A			
Designing for durability and resilience	1	*	0.5	0.5
Material efficiency	1		0.5	0.5
Waste	10			
Construction waste management	3		1.5	1.5
Recycled aggregates	1		*	1

BREEAM	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Operational waste	2		*	2
Speculative floor and ceiling finishes	1	*	*	1
Adaptation to climate change	1	0.33	0.33	0.33
Functional adaptability	1	0.5	0.5	
Land Use and Ecology	10			
Site selection	3			3
The ecological value of site and protection of ecological features	2			2
Minimizing impact on existing site ecology	N/A			
Enhancing site ecology	3			3
Long term impact on biodiversity	2			2
Pollution	13			
Impact of refrigerants	4			4
NOx emissions	2	*		2
Surface water run-off	5			5
Reduction of night time light pollution	1			1
Reduction of noise pollution	1			1
Innovation	10			
Innovation				
Total	155			

Classification of different certification levels as per BREEAM rating benchmarks.

BREEAM Rating	Percentage Score
Outstanding	≥85
Excellent	≥70
Very good	≥55
Good	≥45
Pass	≥30
Unclassified	<30

Green Globes for New Construction.

Green Globes	Maximum Points	Dimension of Sustainability		
		Social	Economic	Environment
Project Management	50			
Integrated Design Process (IDP)	9			9
Environmental Management During Construction	12			12
Commissioning	29			29
Site	115			
Development Area	30			30
Ecological Impacts	32			32
Stormwater Management	18			18
Landscaping	28			28
Exterior Light Pollution	7	7		
Energy	390			
Energy Performance	100			100
Energy Demand	35		*	35
Metering, Measurement, and Verification	12		*	12

Green Globes	**Maximum Points**	**Dimension of Sustainability**		
		Social	**Economic**	**Environment**
Building Opaque Envelope	31			31
Lighting	36	36		
HVAC Systems and Controls	59			59
Other HVAC Systems and Controls	32			32
Other Energy Efficient Equipment and Measures	11		*	
Renewable Energy	50			
Energy Efficient Transportation	24	12		12
Water	110			
Water Consumption	42			42
Cooling Towers	9			9
Boilers and Water Heaters	4			4
Water Intensive Applications	18			18
Water Treatment	3			3
Alternate Sources of Water	5			5
Metering	11		*	11
Irrigation	18			18
Materials and Resources	125			
Building Assembly (core and shell including envelope)	33			33
Interior Fit-outs (Including Finishes and Furnishings)	16			16
Re-use of Existing Structures	26		*	26
Waste	9			9
Building Service Life Plan	7			7
Resource Conservation	6			6
Envelope—Roofing/Openings	10			10
Envelope—Foundation, Waterproofing	6			6
Envelope—Cladding	5			5
Envelope—Barriers	7			7
Emissions	50			
Heating	18			18
Cooling	29			29
Janitorial Equipment	3	3		
Indoor Environment	160			
Ventilation	37	37		
Source Control and Measurement of Indoor Pollutants	46	46		
Lighting Design and Systems	30	30		
Thermal Comfort	18	18		
Acoustic Comfort	29	29		
Total	1000			

Classification of different certification levels as per Green Globes rating for New Construction.

Green Globes Percentage Score	Green Globes Rating	Description
85–100%	4 Globes	Demonstrates national leadership and excellence in the practice of energy, water, and environmental efficiency to reduce environmental impacts.
70–84%	3 Globes	Demonstrates leadership in applying best practices regarding energy, water, and environmental efficiency.
55–69%	2 Globes	Demonstrates excellent progress in the reduction of environmental impacts and use of environmental efficiency practices.
35–54%	1 Globes	Demonstrates a commitment to environmental efficiency practices.
85–100%	4 Globes	Demonstrates national leadership and excellence in the practice of energy, water, and environmental efficiency to reduce environmental impacts.
70–84%	3 Globes	Demonstrates leadership in applying best practices regarding energy, water, and environmental efficiency.

GBI-Non-Residential Building Construction.

GBI	Maximum Points	Dimension of Sustainability		
ENERGY EFFICIENCY	**38**	**Social**	**Economic**	**Environment**
Design & Performance				
Minimum EE Performance	2			2
Lighting Zoning	3			3
Electrical Sub-metering	2			2
Renewable Energy	5			5
Advanced or Improved EE Performance—BEI	15			15
Commissioning				
Enhanced or Re-commissioning	4			4
On-going Post Occupancy Commissioning	2	2		
Monitoring, Improvement & Maintenance				
EE Monitoring & Improvement	2			2
Sustainable Maintenance	3	2	1	
INDOOR ENVIRONMENTAL QUALITY	21			
Air Quality				
Minimum IAQ Performance	1	1		
Environmental Tobacco Smoke (ETS) Control	1	1		
Carbon Dioxide Monitoring and Control	1	1		
Indoor Air Pollutants	2	2		
Mould Prevention	1	1		
Thermal Comfort				
Thermal Comfort: Controllability of Systems	2	2		
Air Change Effectiveness	1	1		
Lighting, Visual & Acoustic Comfort				
Daylighting	2	2		
Daylight Glare Control	1	1		
Electric Lighting Levels	1			1
High-Frequency Ballasts	1	1		
External Views	2	2		
Internal Noise Levels	1	1		
Verification				
IAQ Before/During Occupancy	2	2		

GBI	Maximum Points	Dimension of Sustainability		
ENERGY EFFICIENCY	**38**	**Social**	**Economic**	**Environment**
Occupancy Comfort Survey: Verification	2	2		
SUSTAINABLE SITE PLANNING & MANAGEMENT	10			
Facility Management				
GBI Rated Design & Construction	1	1		
Building Exterior Management	1			1
Integrated Pest Management, Erosion Control & Landscape Management	1			1
Transportation				
Green Vehicle Priority	1			1
Parking Capacity	1			1
Reduce Heat Island Effect				
Greenery & Roof	4			4
Building User Manual	1			1
MATERIALS & RESOURCES	9			
Reused & Recycled Materials				
Material Reuse and Selection	1	1		
Recycle Content Materials	1			1
Sustainable Materials & Resources and Policy				
Sustainable Timber	1	1		
Sustainable Purchasing Policy	1		1	
Waste Management				
Storage, Collection & Disposal of recyclables	3			3
Green Products				
Refrigerants & Clean Agents	2			2
WATER EFFICIENCY	12			
Water Harvesting & Recycling				
Rainwater Harvesting	3			3
Water Recycling	2			2
Increased Efficiency				
Water Efficient—Irrigation/Landscaping	2			2
Water Efficient Fittings	3			3
Metering & Leak Detection System	2			2
INNOVATION	10			
Innovation & Environmental Initiatives	9			9
Green Building Index Facilitator	1	1		

Classification of different certification levels as per GBI-Non-Residential Building Construction.

Points	GBI Rating
86–100	Platinum
76–85	Gold
66–75	Silver
50–65	Certified

GSAS Design & Build Certification.

GSAS	Maximum Points	Dimension of Sustainability		
Urban Connectivity	0.180	Social	Economic	Environment
Proximity to infrastructure				
Proximity to amenities				
Load on local traffic conditions				

GSAS	Maximum Points	Dimension of Sustainability		
Urban Connectivity	**0.180**	**Social**	**Economic**	**Environment**
Public transportation				
Green transportation				
Neighbourhood acoustics				
Site	0.510			
Land preservation				
Waterbody preservation				
Biodiversity preservation				
Vegetation				
Drain and stormwater contamination				
Rainwater runoff				
Heat island effect				
Shading				
Accessibility				
External lighting				
Light pollution				
Noise pollution				
Eco-Parking				
Mixed use				
Construction practices				
Energy	0.720			
Thermal energy demand performance				
Energy use performance				
Primary energy performance				
CO_2 emissions				
Energy sub-metering			*	
Water	0.480			
Water demand performance				
Water reuse performance				
Water sub-metering				
Materials	0.270			
Locally sourced material			*	
Material eco-labelling			*	
Recycled content of materials			*	
Material reuse			*	
Existing structure reuse			*	
Design for disassembly			*	
Responsible sourcing of material			*	
Indoor Environment	0.570			
Thermal comfort				
Natural ventilation				
Mechanical ventilation				
Lighting				
Daylight				
Glare				
Views				
Acoustics				
Low VOC-materials				
Airborne contaminants				

GSAS	Maximum Points	Dimension of Sustainability		
Urban Connectivity	**0.180**	**Social**	**Economic**	**Environment**
Cultural & Economic Value	0.120			
Heritage and cultural identity				
Support of national economy				
Management and Operations	0.150			
Systems commissioning				
Waste management				
Facility management				
Leak detection systems				
Automated control systems				
Transportation systems in building				
Total	3.0			

* Category weight is divided equally among the category parameters. For example, the Site category points are 0.510 and there are 15 category parameters hence score assumed for each parameter is 0.510/15 i.e., 0.034.

Classification of different certification levels as per GSAS Design & Build.

Score	Rating
X < 0	Certification denied
$0.00 \leq X \leq 0.50$	*
$0.50 < X \leq 1.00$	**
$1.00 < X \leq 1.50$	***
$1.50 < X \leq 2.00$	****
$2.00 < X \leq 2.50$	*****
$2.50 < X \leq 3.0$	******

Appendix B

Table A1. Table of explanation refered from Table 2 in maintext.

Social Sustainability Parameters (Phase 1. Conceptual Planning and Feasibility Study)	
Parameters	**Further Explanation**
Stakeholders' consultation and engagement	• Expectations of the owner, designer, and public early in the project i.e., community relationship and involvement • Informing stakeholders about the project constraints like budget, schedule, location, size, design, and construction standards i.e., well-defined project scope and limitations • Ensure participation of final users in design for understanding and anticipating their needs i.e., social apprehension of their needs-social design • Establish partnering strategies for resolving interpersonal conflicts among project stakeholders • The minimized project caused nuisances and disruptions like dust, noise, traffic, and others • Provisions for public safety like barricading, signboards, and others • Protecting local heritage (natural and cultural) from project's negative impact • Empowering of young people, women, disadvantaged with better job opportunities, the creation of green jobs, and the conditions needed to create them i.e., sustainable employment • Awareness training for social and environmental sustainability and education/training for skill development • Concern for users' safety, health, productivity, privacy, and security Accessibility of built facility through rail/road/public transit systems, universal accessibility through disabled-friendly features

Table A1. *Cont.*

Social Sustainability Parameters (Phase 1. Conceptual Planning and Feasibility Study)	
Parameters	**Further Explanation**
Health and safety considerations	• Planning for worker's facilities such as drinking water, sewage, and solid waste management, and others • Planning for female worker's specific health and safety facilities • Conducting safety assessment/planning to identify any future risk/safety issues to public and safety users
Ethical considerations	• Corruption incidents' monitoring and prompt action against unethical conduct • Organizational ethics anti-competitive and fair bidding practices • Disclosure towards anti-corruption measures • Compliance with regulations to overcome ethical lapses • Leadership appointments involving ethical considerations i.e., avoiding any conflict of interest
Social Sustainability Parameters (Phase 2. Design and Engineering)	
Parameters	**Further Explanation**
Health, wellbeing, and the environment	• Design for better health and surrounding environment to promote activity indoors and outdoors, and encourage physical health of occupants • Design for better lifestyle practices, including nutrition, hydration, and social connectivity for the occupants • Design for reducing infectious disease transmission within constructed facility environment
Social Sustainability Parameters (Phase 3. Construction)	
Parameters	Further Explanation
Socio-economic strategies for workers	• Ensure health (both physical and mental) and safety of workers by minimizing unsafe acts and unsafe conditions like exposure to hazardous materials, chemicals, carcinogenic substances, and others • Empowerment of females and promote gender equality among construction workforce • Protect labour rights, ensure the workforce is free from forced, trafficked, and child labour • Ensure safe, clean, and habitable living conditions for workers · Ensure access to grievance redressal mechanism for workers • Education schemes for construction workers for improving literacy and skills especially targeting workers in certain geographies who are working since childhood • Educating workers for continuous awareness about carbon-neutral technologies and sustainability practices
Social Sustainability Parameters (Phase 4. Operation and Maintenance)	
Parameters	**Further Explanation**
Prioritizing occupant's comfort	• Ensuring thermal comfort during the operational phase • Ensuring natural and energy-efficient lighting solutions during the operational phase • Ensuring acoustic comfort during the operational phase • Ensuring olfactory, ergonomics, and visual comforts during the operational phase • Ensure universal access to different ability people during the operational phase

Table A1. *Cont.*

Social Sustainability Parameters (Phase 5. End-of-life)	
Parameters	**Further Explanation**
Effective project communication	• Disclosure to the public about dismantling process and digital dissemination about the same • Disseminating information of building materials and components and communicating with planners, construction workers, and other active professionals • Disseminating information on effects on local environment and measures taken to mitigate the same • Managing communication among the stakeholders
Security	• Ensure work and safety plan for the contaminated and non-contaminated area • Ensure implementation of construction site ordinance • Ensure accessibility of the site only to the authorized persons via protective measures

Table A2. Table of explanation refered from Table 3 in maintext.

Economic Sustainability Parameters (Phase 5. End-of-Life)	
Parameters	**Further Explanation**
Values of expandable resources	• Estimating potential expandable components and products, fixtures, and furniture • Assessing the components and construction products potentially expandable • Proactive analysis of identified potential expandable components and fixtures • Market analysis of identified potential expandable components and fixtures
Separation, recycling, and disposal	• Ensure characterization of material and designation of quality levels • Measures to minimize the accumulated rubble/mixed construction waste whose separation is technically and economically not feasible • Optimization of disposal and recycling routes • Measures for pure separation, circular use, and storage in material banks

Appendix C

Illustrative example highlighting the advantage of the proposed PWBDI/PIDI approach

Consider two projects which are evaluated using the GRIHA system, which assigns maximum credits of 24, 5 and 71 to social, economic, and environmental assessment respectively. The scores achieved by the two projects under the different sustainability dimensions are as given in the following table.

Description	Sustainability Dimension		
	Social	Economic	Environment
Maximum credits	24	5	71
Assumed performance score-PROJECT 1	14	1	65
Assumed performance score-PROJECT 2	9	3	68

GRIHA rating for both the projects would be "****" based on aggregate score of 80. Project 1 scored low on economic assessment (20%) but still achieved "****" while Project 2 scored low on social assessment (37.5%) and still achieved "****". To judge whether both the Project 1 and Project 2 are equally sustainable or one is more/less compared to other is critical. Hence, taking a simple 'arithmetic sum' of three scores and having that sum clear a pre-determined benchmark leaves a possibility of extremely low scores in one (or even two) dimension(s) and still qualifying for a high rating. This inherent lacuna is addressed by defining and adopting the PWBDI and PIDI approach as illustrated in following tables.

GRIHA scores in pre-construction phase.

Description	Sustainability Dimension		
	Social	Economic	Environment
Max. Credits	24	5	71
Assumed performance score-PROJECT 1	14	1	65
Assumed performance score-PROJECT 2	9	3	68
Normalized performance score-PROJECT 1	0.58	0.20	0.91; environment non-conformance = 1 − 0.91 = 0.09
Normalized performance score-PROJECT 1	0.37	0.6	0.96; environment non-conformance = 1 − 0.96 = 0.04
Base phase chain number-PROJECT 1	1	1	1
Base phase chain-PROJECT 1	1	1	1

GRIHA scoring in construction phase.

Description	Sustainability Dimension		
	Social	**Economic**	**Environment**
Max. Credits	24	5	71
Assumed performance score-PROJECT 1	17	2	61
Assumed performance score-PROJECT 2	11	2	67
Normalized performance score-PROJECT 1	0.71	0.4	0.86; environment non-conformance = 1 − 0.86 = 0.14
Normalized performance score-PROJECT 2	0.46	0.4	0.94; environment non-conformance = 1 − 0.94 = 0.06
Current phase chain number -PROJECT 1	1.22	2	1.55
Current phase chain number -PROJECT 2	1.24	0.67	1.5
PWBDI Scenario -PROJECT 1	0.79		
Remark -PROJECT 1	As SOPn > 1, ENPn > 1 and PWBDI < 1; It indicates that as the project-1 moves from pre-construction to construction phase, increase in social well-being is coupled with increasing environmental pressure		
PIDI -PROJECT 1	1.29		
Remark -PROJECT 1	As ECPn > 1, ENPn > 1 and PIDI > 1; It indicates that as the project-1 moves from pre-construction to construction phase, increase in economic well-being exceeds the increase in environmental pressure		
PWBDI -PROJECT 2	0.83		
Remark -PROJECT 2	As SOPn > 1, ENPn > 1 and PWBDI < 1; It indicates that as the project-2 moves from pre-construction to construction phase, increase in social well-being is coupled with increasing environmental pressure		
PIDI -PROJECT 2	0.44		
Remark -PROJECT 2	As ECPn < 1, ENPn > 1 and PIDI < 1; It indicates that as the project-2 moves from pre-construction to construction phase, economic well-being decreases with increase in environmental pressure		
Description	**GRIHA Rating Based on Aggregate Score (Pre-Construction → Construction)**		**Interpretation Based on PWBDI/PIDI Approach (PWBDI, PIDI)**
Project-1	**** → ****		(0.79, 1.29)
Project-2	**** → ****		(0.83, 0.44)
	Non-desirable state, which could not have been detected by mere aggregate scoring as offered by these rating tools/schemes		

It may be noted that based on aggregate scores different scenarios are possible and moreover when these projects move from one phase to other phase, they can behave differently irrespective of their base phase performance as illustrated by PWBDI and PIDI for the above two projects.

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