Practical application of a system dynamics-based sustainability benchmarking in the building sector: Case of Affordable Housing in India

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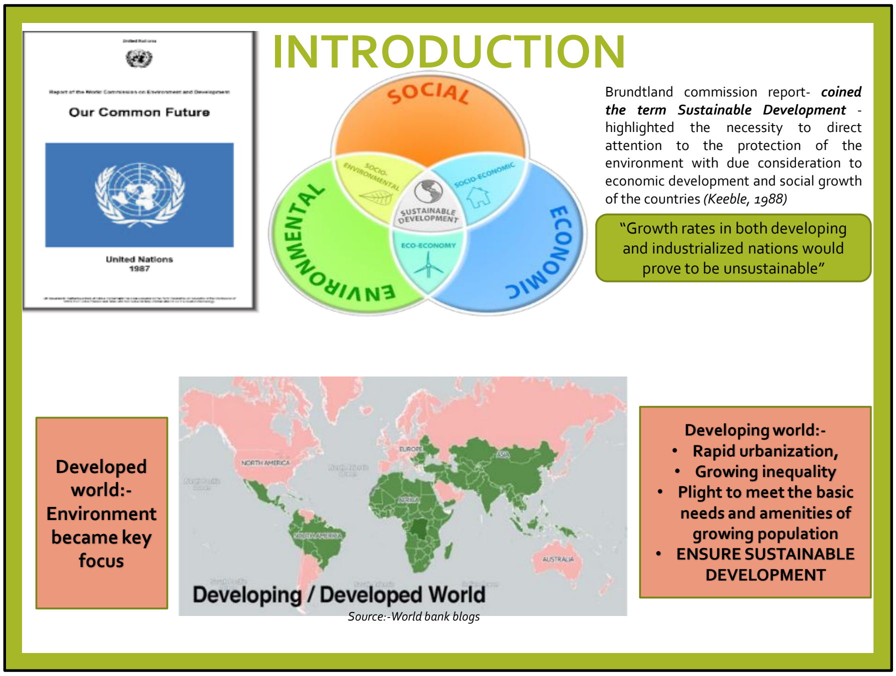
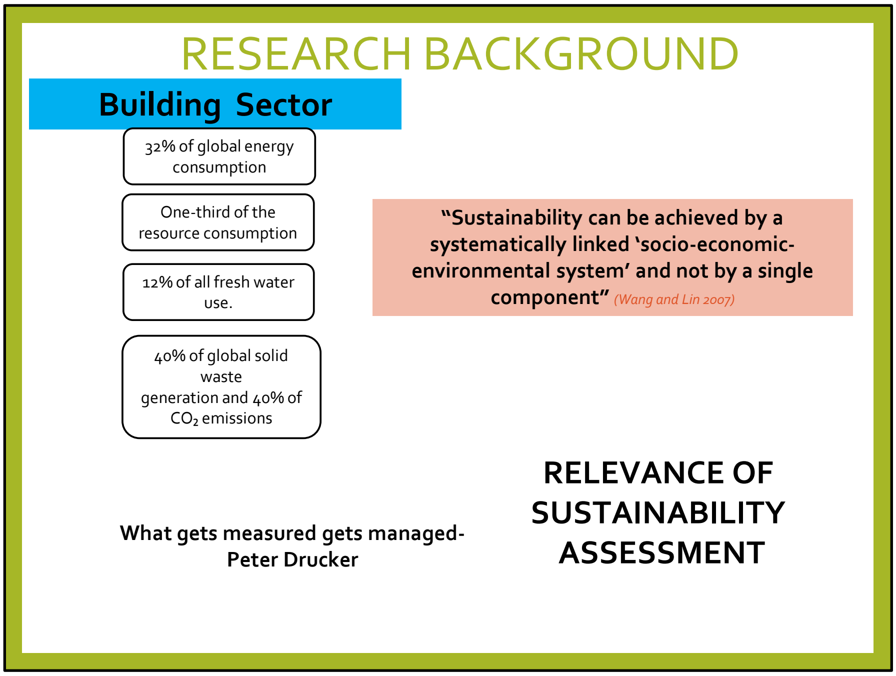


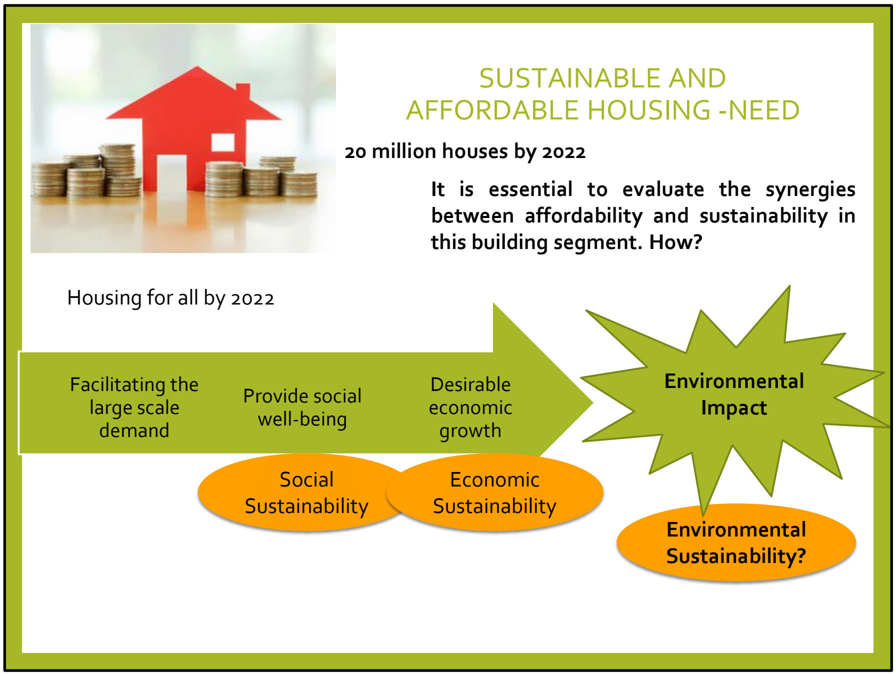
In its 96th plenary meeting in 1987, the Brundtland Commission, established by the United Nations (UN), expressed concern about the deteriorating natural ecosystem and its influence on economic and social development. Following this, the UN adopted sustainability as its guiding principle to ensure that the needs of the present generation are fulfilled by giving due consideration to the future generation. The report highlighted the need for economic development and social growth in the countries while duly addressing environmental concerns. Thereafter, developed nations have directed significant attention to the environmental aspect of sustainability because of their upfront progress in the social and economic dimensions. On the contrary, ensuring sustainability becomes a challenge for developing nations due to the aggravating problems of rapid urbanization, growing inequality, and plight to meet the basic needs and amenities demanded by their ever-growing population.



For these emerging economies, the buildings and infrastructure sector significantly influence national growth and prosperity in the form of its contribution to the Gross Domestic Product (GDP), creation of employment opportunities, and improvement of the overall quality of living. However, meeting these building and infrastructural demands would mean a significant impact on the environment as their construction would lead to massive greenhouse gas (GHG) emissions, extraction of several natural resources, and consumption of a major share of the primary energy. Hence, developing nations that need to construct more infrastructure and buildings to sustain economic growth and social well-being are further compelled to be more cautious about the associated environmental impacts. In this background, the need to measure sustainability garnered significant attention owing to the understanding that "what gets measured gets managed" (Drucker 1954). Hence, it is essential to measure sustainability to ensure it is achieved effectively. Therefore the building sector, with its growing relevance in the coming years, especially in emerging economies, requires to engage in 'sustainability assessment,' which includes tools/frameworks that help quantify a product's or a process's environmental, social, and economic impacts

If this industry is able to embrace practices which promote sustainaility and amend its policies, regulations, and management practices accordingly, the pace for sustainable development for these countries will be faster-

With enhanced attention on the need for **affordability** and **sustainability** to be achieved simultaneously in the building sector in a socially inclusive manner; economies need to adopt necessary strategies to achieve the committed targets.



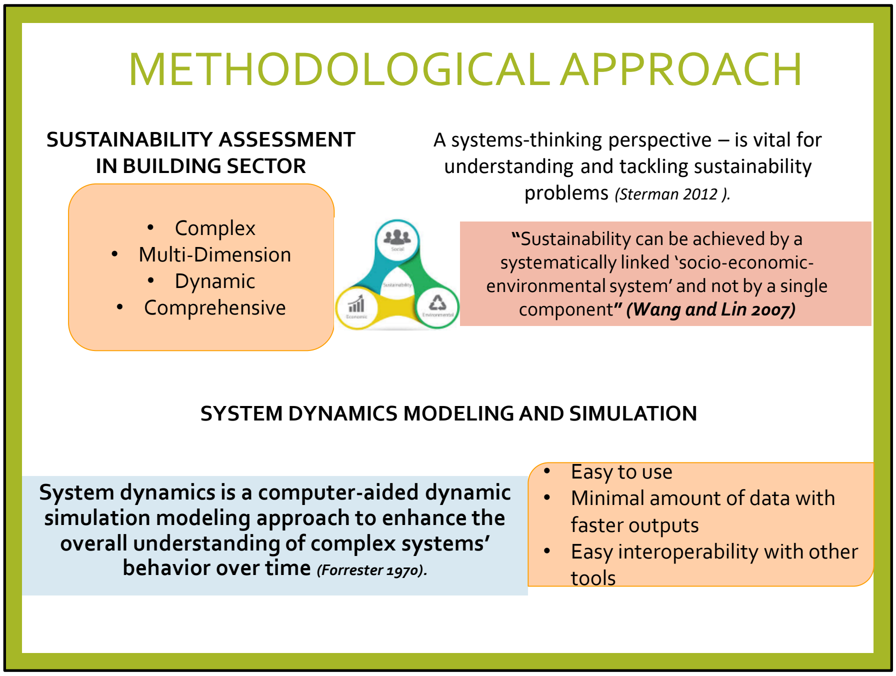
In 2015, the government of India announced a highly ambitious program ‘’. It aims at providing affordable housing to the urban poor by building about.

The committee engaged in promoting affordable housing of the Ministry of Housing and Urban Poverty Alleviation (MHUPA) has defined affordable housing as - "any housing that meets some form of affordability criterion, which could be income level of the family, size of the dwelling unit or affordability in terms of EMI size or ratio of house price to annual income

Grant of Infrastructure status helps access cheaper and easier financing mechanisms.

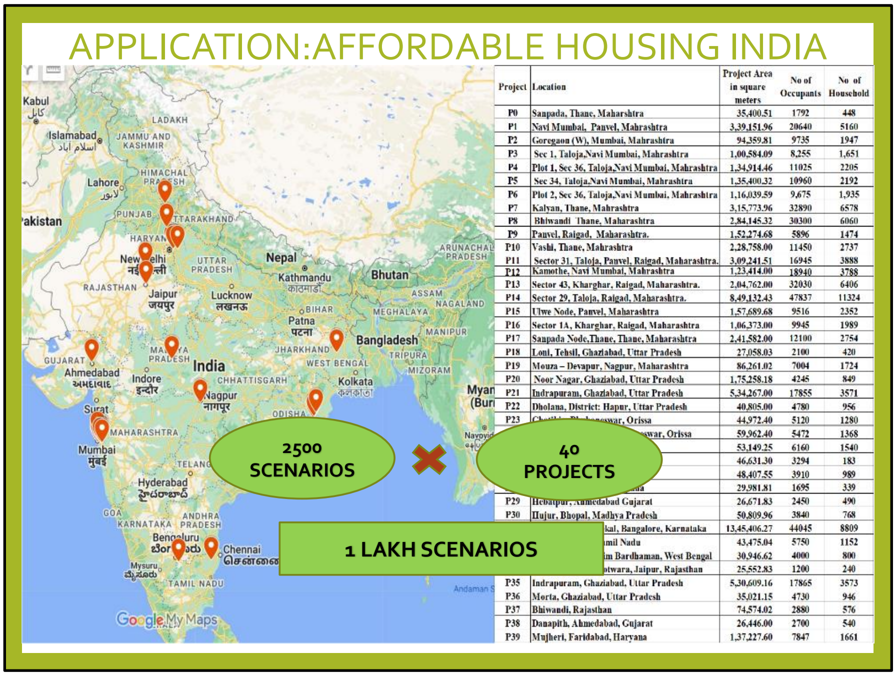
Public Private Partnership Model in affordable housing. Facilitating the large scale demand of affordable housing would provide social well-being and the desirable economic growth to the country.

Such large scale construction would also lead to: a large amount of resource consumption, depletion of natural resources, soil erosion, climate change and other adverse environmental impacts.



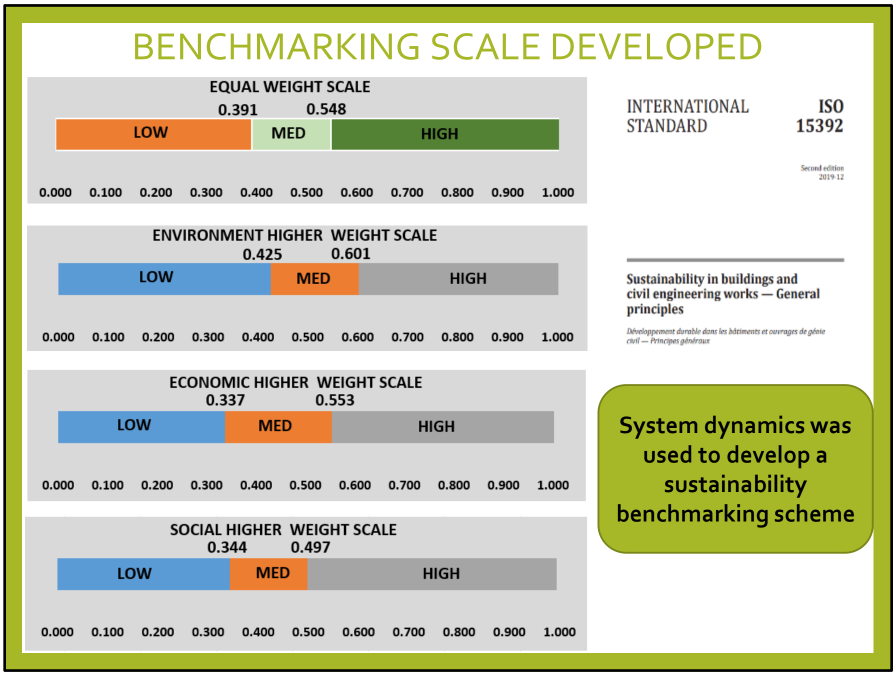
The existing sustainability assessment frameworks/tools in the building sector exhibit limitations in evaluating interdependencies and trade-offs among the sustainability pillars and accounting for dynamic (time-induced) changes in buildings. Such sustainability evaluation is complex, multi-faceted, and data-intensive. However, the literature review suggested that systems thinking could help solve several sustainability problems due to its ability to understand the interaction between systemic components and analyze complex system behavior (Sterman 2012). Therefore, system dynamics modeling and simulation that provides a computational platform to implement systems thinking is an ideal methodological approach. It would help evaluate building sustainability by accounting for the interconnections and time-induced changes that occur during the building lifespan. Hence, it forms the core methodology of this research.

PRACTICAL APPLICATION OF THE SYSTEM DYNAMICS BASED SUSTAINABILITY EVALUATION AND BENCHMARKING FRAMEWORK



Project	Location	Project Area in square meters	No of Occupants	No of Household
P0	Sanpada, Thane, Maharshtra	35,400.51	1792	448
P1	Navi Mumbai, Panvel, Mahrashtra	3,39,151.96	20640	5160
P2	Goregaon (W), Mumbai, Mahrashtra	94,359.81	9735	1947
P3	Sec 1, Taloja,Navi Mumbai, Mahrashtra	1,00,584.09	8,255	1,651
P4	Plot 1, Sec 36, Taloja,Navi Mumbai, Mahrashtra	1,34,914.46	11025	2205
P5	Sec 34, Taloja,Navi Mumbai, Mahrashtra	1,35,400.32	10960	2192
P6	Plot 2, Sec 36, Taloja,Navi Mumbai, Mahrashtra	1,16,039.59	9,675	1,935
P7	Kalyan, Thane, Mahrashtra	3,15,773.96	32890	6578
P8	Bhiwandi Thane, Maharashtra	2,84,145.32	30300	6060
P9	Panvel, Raigad, Maharashtra.	1,52,274.68	5896	1474
P10	Vashi, Thane, Mahrashtra	2,28,758.00	11450	2737
P11	Sector 31, Taloja, Panvel, Raigad, Maharashtra.	3,09,241.51	16945	3888
P12	Kamothe, Navi Mumbai, Mahrashtra	1,23,414.00	18940	3788
P13	Sector 43, Kharghar, Raigad, Maharashtra.	2,04,762.00	32030	6406
P14	Sector 29, Taloja, Raigad, Maharashtra.	8,49,132.43	47837	11324
P15	Ulwe Node, Panvel, Maharashtra	1,57,689.68	9516	2352
P16	Sector 1A, Kharghar, Raigad, Maharashtra	1,06,373.00	9945	1989
P17	Sanpada Node,Thane, Thane, Maharashtra	2,41,582.00	12100	2754
P18	Loni, Tehsil, Ghaziabad, Uttar Pradesh	27,058.03	2100	420
P19	Mouza – Devapur, Nagpur, Maharashtra	86,261.02	7004	1724
P20	Noor Nagar, Ghaziabad, Uttar Pradesh	1,75,258.18	4245	849
P21	Indrapuram, Ghaziabad, Uttar Pradesh	5,34,267.00	17855	3571
P22	Dholana, District: Hapur, Uttar Pradesh	40,805.00	4780	956
P23	[illegible]war, Orissa	44,972.40	5120	1280
[illegible]	[illegible]swar, Orissa	59,962.40	5472	1368
[illegible]	[illegible]	53,149.25	6160	1540
[illegible]	[illegible]	46,631.30	3294	183
[illegible]	[illegible]	48,407.55	3910	989
[illegible]	[illegible]	29,981.81	1695	339
P29	[illegible], Ahmedabad Gujarat	26,671.83	2450	490
P30	Hujur, Bhopal, Madhya Pradesh	50,809.96	3840	768
[illegible]	[illegible]kal, Bangalore, Karnataka	13,45,406.27	44045	8809
[illegible]	[illegible]mil Nadu	43,475.04	5750	1152
[illegible]	[illegible]m Bardhaman, West Bengal	30,946.62	4000	800
[illegible]	[illegible]otwara, Jaipur, Rajasthan	25,552.83	1200	240
P35	Indrapuram, Ghaziabad, Uttar Pradesh	5,30,609.16	17865	3573
P36	Morta, Ghaziabad, Uttar Pradesh	35,021.15	4730	946
P37	Bhiwandi, Rajasthan	74,574.02	2880	576
P38	Danapith, Ahmedabad, Gujarat	26,446.00	2700	540
P39	Mujheri, Faridabad, Haryana	1,37,227.60	7847	1661

The SAB framework proposed for the building sector through this research could be applied across a wide range of projects of different kinds. However, given the massive scale and need to direct serious efforts into enhancing the sustainability of the affordable housing segment, it was an ideal case of an application for sustainability benchmarking. Therefore, 40 PMAY-urban projects (based on the availability of detailed project reports on the environmental clearance website were chosen to create the building database to develop the benchmarking scale. These projects have a per unit area varying between 30-120 square meters, mainly catering to the LIG and MIG category. About 50 % of these projects chosen are from the western state of Maharashtra, owing to the highest number of houses sanctioned under the proposed scheme and data availability in a public database. However, PMAY projects from geographically diverse locations are chosen from across the country to account for the influence of location on sustainability performance. The SAB framework takes inputs of location, built-up area, project phase duration, materials, electricity grid emission factors for each state, and the garden or green area proposed. It computes the sustainability of each of these projects based on the parameters and variables defined for the various sub-models depending on the type of the project. The details of location, built-up area, green cover, the number of people (households, occupants, and workers), and the five primary materials (cement, fine aggregate, coarse aggregate, steel, bricks) of each building are considered as inputs to the framework. Therefore, the sub-model variables and parameters specified before were plugged into the system dynamics interface using the data available on PMAY projects. Additionally, the input data for these 40 PMAY is simulated throughout all life cycle phases. This covers the production of phase of the material (2 years), which is part of the typical construction phase (4 years), the building use period (50 years), and the end-of-life phase (1 year). Several simulation runs are initiated for the base case of the projects while keeping in mind the stochastic character of the system dynamics models due to the nature of various governing variables such as water consumption, costs, transport distances, and energy consumption. Following the base case analysis, testing and validation are conducted to compare the results with information on past research of a similar nature. Once the models are built with the help of these parameters and variables and incorporated with several interventions for sustainability, the buildings are subject to a series (2500) of policy scenarios for sustainability improvement

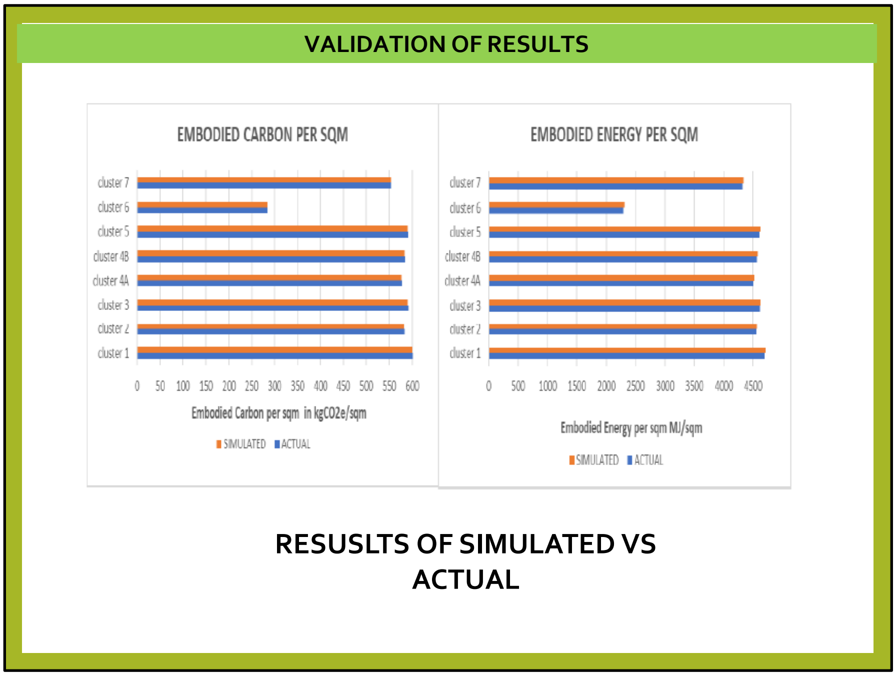


The benchmarking scale developed for different weighting criteria.

APPLICATION ON A PROJECT FOR DECISION MAKING

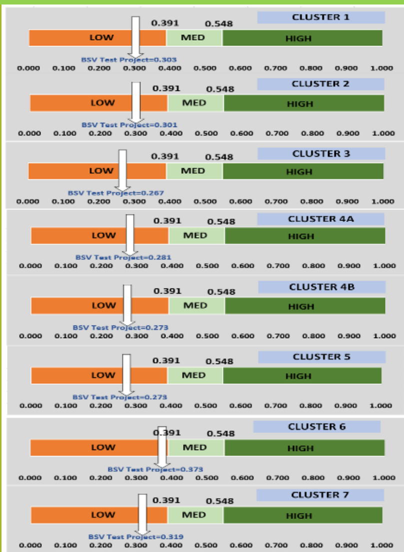
SANJAYNAGAR AFFORABLE HOUSING UNDER PMAY SCHEME

A PMAY project from Maharashtra was chosen for which the data on actual sustainability parameters were obtained to be compared with the simulation results generated from the SAB framework. Further, the different clusters in the project were tested in the benchmarking scale, and relevant sustainability improvement strategies were recommended. The project on which the framework was implemented is the Sanjaynagar slum rehabilitation project, an in-situ slum redevelopment project located in Ahmednagar, a Tier-3 district in Maharashtra state



From the embodied energy and carbon details, it is clear that the share of the five primary materials (cement, sand, steel, bricks/blocks, and aggregate) in this project is about 92% and 88%, respectively. Hence, the SAB framework, designed based on these five materials, is directly applied to this project by focusing on these five primary materials alone. Therefore, for initial validation, the initial embodied energy and carbon per unit area obtained from the data from the site were compared with the results from the simulation interface. The values were found to be reasonably close,

RESULTS OF THE BENCHMARKING SCHEME

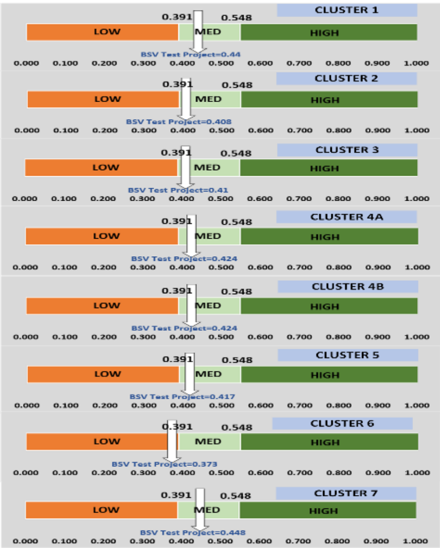


ORIGINAL PLAN

- The results show that cluster 6, completed using a vernacular plank and joist construction technology, has a superior sustainability performance compared to the other clusters that propose confined masonry.
- This is synonymous with the embodied energy and embodied carbon data available from the site. However, this cluster is observed to have a higher REE than others because of the need for replacement and repainting of the joists and planks or stone in about 15-20 years. The other clusters need only minimal maintenance.
- The initial plan was to build all the buildings using similar region-specific vernacular technologies.
- As the construction of cluster 6 progressed, it was clear that the skill sets required to execute a project using such technologies were not sufficiently available.
- Although the test results in the original plan indicated that the vernacular technology in its current form is superior in terms of sustainability across these indicators.
- However, considering the practical difficulties and the repair and maintenance efforts involved, the project's decision-makers plan to adopt confined masonry for the remaining clusters.
- However, the benchmarking framework proposed serves as a guide to introduce a few additional strategies to improve the performance of the remaining clusters.

RESULTS OF THE BENCHMARKING SCHEME

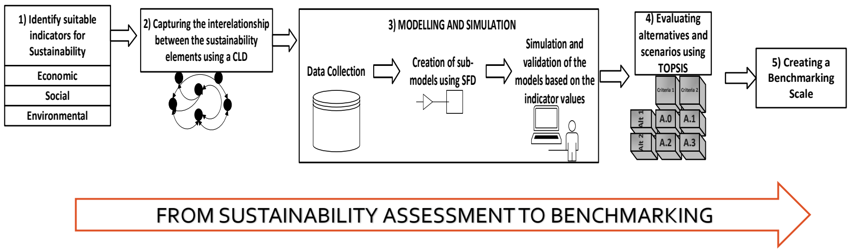
- The revised plan shows the updated benchmarking scheme of the clusters (except cluster 6, which is already constructed) incorporated with a few minimal improvement measures suggested.
- Hence, if the new clusters are constructed with 100% pozzolanic or blended cement within the permissible limits, along with 20% rainwater harvesting and 30% renewable energy facilitation for common area lighting and water heating purposes, these projects could exhibit better performance on the benchmarking scales.
- These measures involve only minimal additional funding but are very easily implementable.
- It would further justify the replacement of sustainable vernacular technology with modern technology in these clusters yet to be constructed.
- This shows that sustainability-based decision-making could be improved with the help of such a benchmarking scheme, and therefore, decisions could be improved in the early planning stages of projects itself.



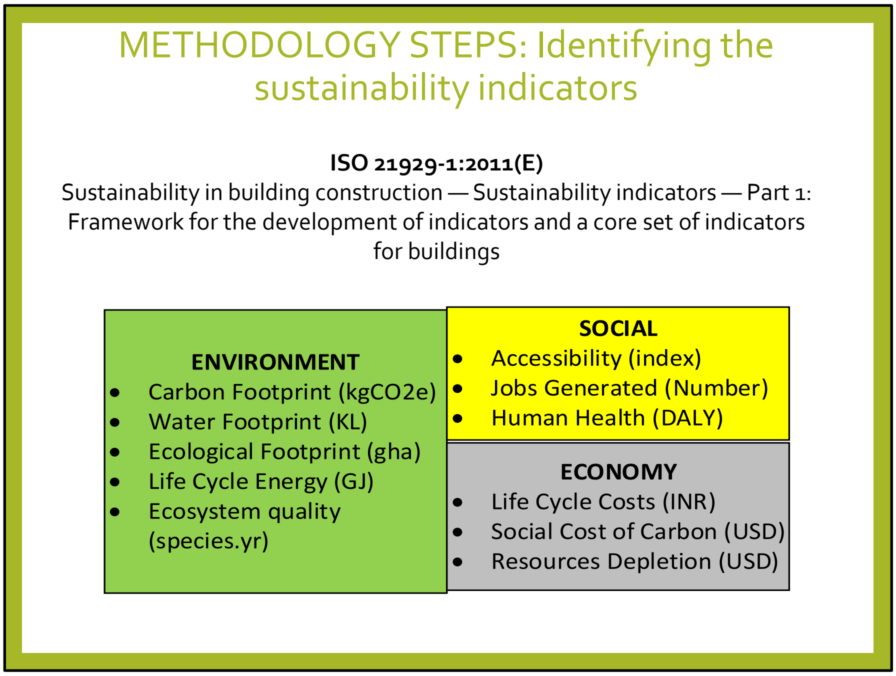
REVISED PLAN

DETAILED METHODOLOGICAL APPROACH

METHODOLOGY

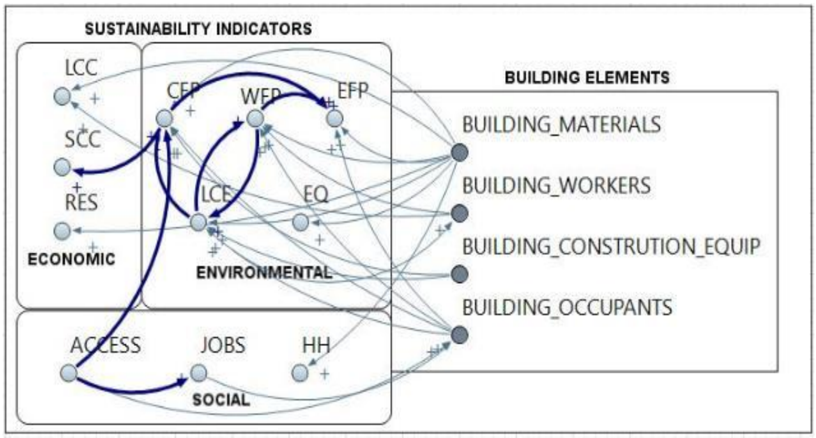


Benchmarking in the building industry would imply a set of criteria or reference points against which the performance of a building may be assessed and compared to industry standards and best practices to improve its overall sustainability



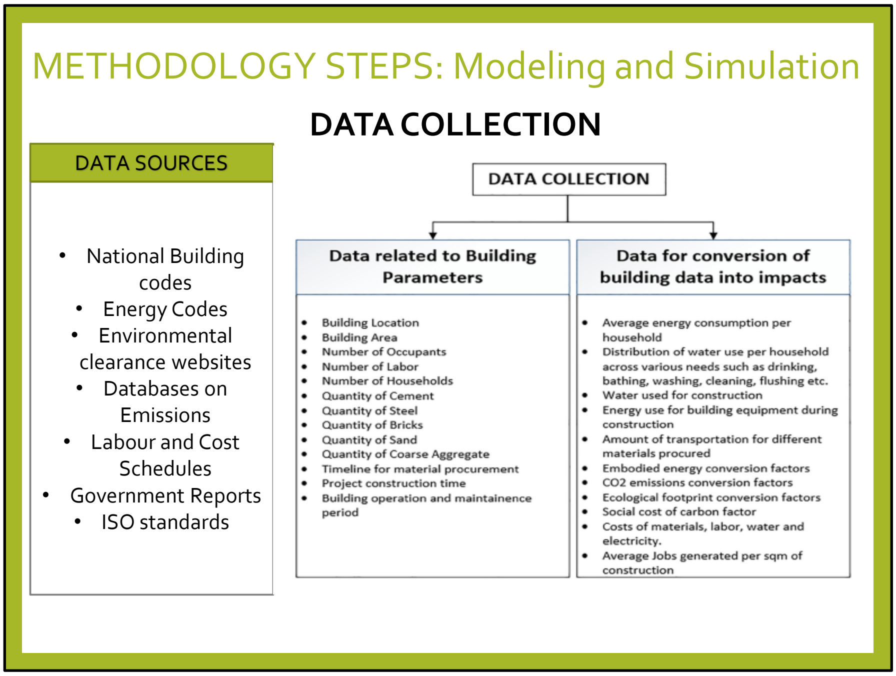
The first step in developing the framework is to select quantitative, standardized, and widely used indicators that affect building sustainability. They were chosen in a way that shows clear interdependencies and allows for an acceptable quantitative representation of the sustainability performance of buildings. As a result, the indicators were chosen based on their association with buildings and their ability to capture dynamic effects on the sustainability of a project at the early stages of project design .

METHODOLOGY STEPS: Developing Causal Loop Diagrams

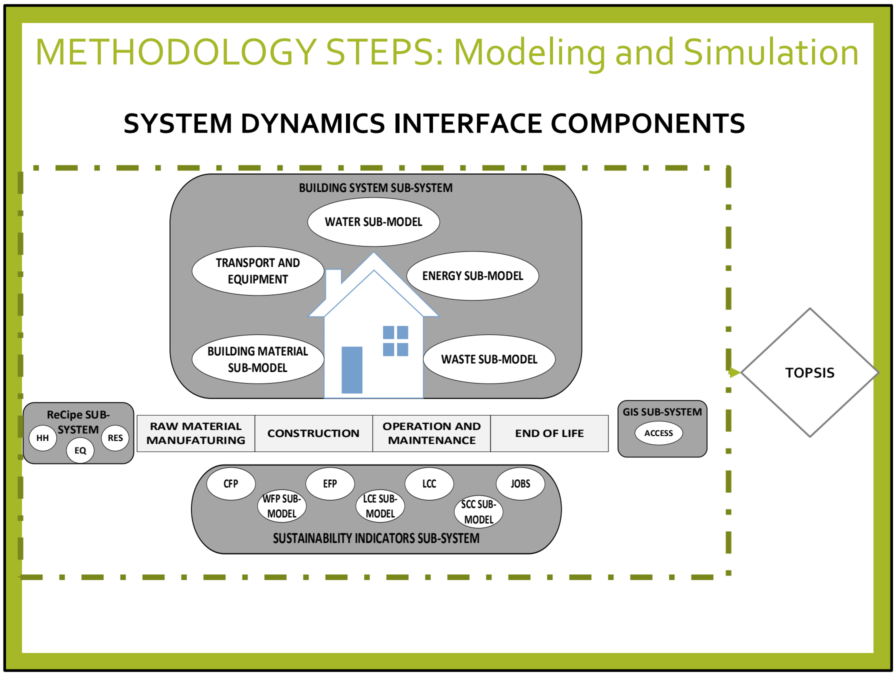


The second step in the methodology is to create a Causal Loop Diagram (CLD) to comprehend the various components of a building's sustainability system and how they interact and behave as a whole. CLD depicts the qualitative connections between different system components. The CLD illustrates the interconnections among the building components (materials, people, and equipment) and the sustainability indicators (grey lines), as well as the linkages between the three sustainability pillars (dark blue lines). A building project uses materials, energy, and water and involves transportation, and waste generation, all of which have an impact on various sustainability indicators in varying degrees. Building construction typically has increased economic, social, and environmental repercussions; therefore, it is known that the building elements influence almost all the indicators through a reinforcing link. The ecological footprint is directly influenced by the carbon and water footprint. Water footprint and carbon footprint are indirectly related. For instance, energy use during wastewater treatment impacts carbon footprint. Additionally, as water use increases, so does energy use (more energy is required to pump or provide water), and as energy use increases, so does the water footprint (due to increased usage of cooling water in thermal energy production). Additionally, since energy use implies emissions from energy production, LCE affects the carbon footprint. Hence, these above linkages show how the water footprint, CFP, and LCE interact. Similarly, carbon emissions directly impact the social cost of carbon).

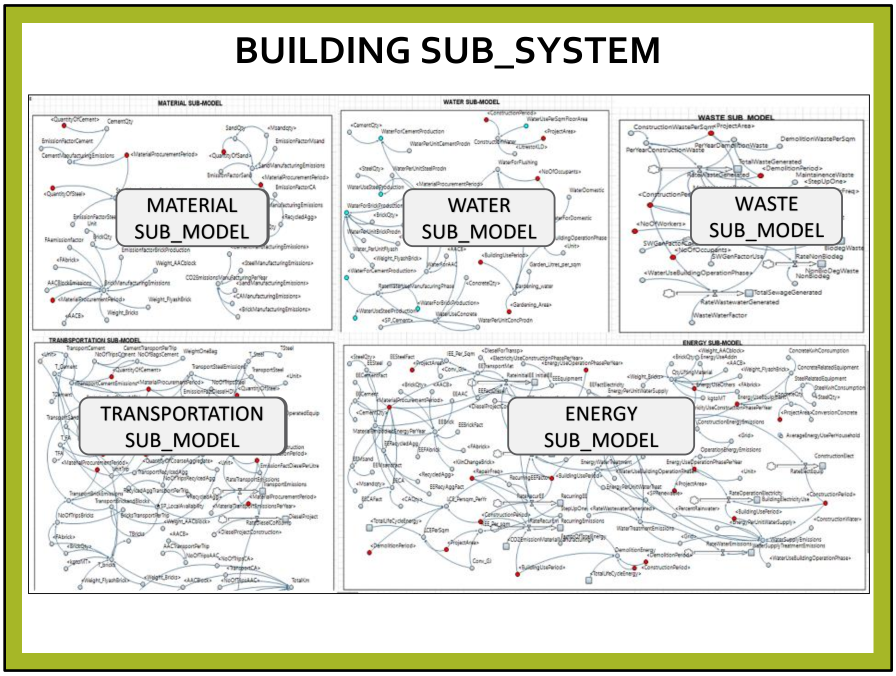
contrast, energy consumption, material use, and water use influence the LCC. Additionally, accessibility to essential facilities influences job-generating potential, transport emissions, and carbon footprint. Accessibility has a direct impact on the environment in terms of carbon emissions and has an impact on jobs, which indirectly has an impact on economic growth.



Developing the system dynamics interface is the next important step in developing the dynamic sustainability assessment framework. For framework development, the AnyLogic (Version 8.5.2) software, which is a multi-method simulation platform built in Java to facilitate the system dynamics modeling, is used. The first step in the system dynamics interface development is data collection. Data on basic building characteristics and details on a building's sustainability are acquired from a wide range of sources. The building's location, construction materials, number of households, residents, and workers, as well as how long it took to acquire the resources and to construct and maintain it, are all part of the data collected. These data serve as input parameters to the system dynamics framework. The other category of standard sustainability-related data includes waste generation per unit area, average transportation needed for material procurement and equipment movement, average energy consumption per unit area, and the amount of water used for various uses. This data is primarily used in the development of the framework. Additionally, depending on the type of building, general information about energy use, emissions, and transportation is gathered from government reports by pollution control boards, ministries responsible for environmental and social management, information published by international organizations such as the International Finance Corporation (IFC), European Union (EU), and United Nations (UN), as well as from publicly available codes and standards. Additionally, actual site data could be added whenever it is accessible. Due to the fact that these data are utilized to model the interactions between the sustainability variables in the framework, the framework could be applied to a wide range of building projects.



The next step in interface development is to develop stock-flow diagrams (SFD) using the data collected. Sub-systems and sub-models are different components of the system dynamics interface that interact with each other. Sub-models are SFDs that operate independently and collaborate with other sub-models as a component of a larger framework



The building sub-system considers the information gathered on building parameters, including materials, project built-up area, equipment, and the number of workers, occupants, and households. This data is then used as input for the various sub-models. The building sub-system takes into account the direct effects of building construction on material, water, energy, transportation, and waste generation, which serve as the basic sub-models. These sub-models communicate with one another based on the linkages established earlier by the CLD and are characterized by stocks, flows, and dynamic variables

Building Material Sub-model

The material sub-model processes the influence of construction materials used in a building on sustainability performance. Therefore, the pressures on the environment resulting from material manufacturing are computed in the material sub-model to determine the flow rate of different sustainability indicators.

Water Sub-model

The water sub-model quantifies the water consumption across the different phases of the project's life cycle to understand the impact on water resources due to a building project. For this purpose, the water used during the raw material manufacturing phase is accounted for during the material procurement period. Similarly, all the water consumption during the construction phase, which mainly includes water for curing, material mixing, and labor uses, is also quantified. Further, the water consumption during the project use period is accounted for using databases of water consumption for different types of building projects.

Energy Sub-model

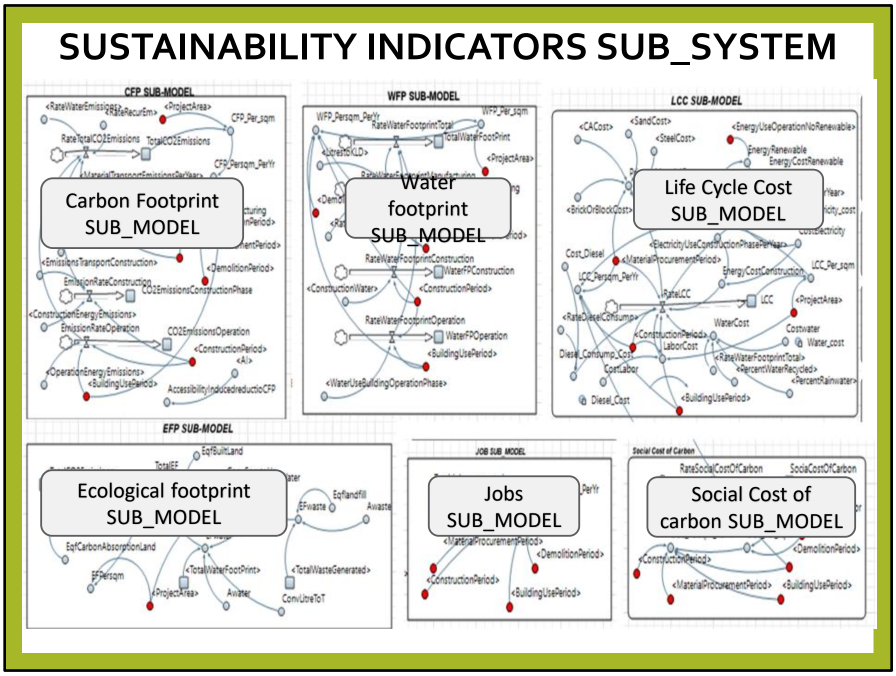
This sub-model is dedicated to calculating the energy requirements at each phase, thereby enabling better energy evaluation of the building. It facilitates quantifying the energy use during the material and construction phase as the IEE. Further, the operation energy is also accounted for in this sub-model. However, here it incorporates the time-induced variation in electricity consumption as per the projected scenarios published for the country and available databases. The REE and DE are commonly considered as a percentage of the IEE and LCE, respectively.

Transport and Equipment Sub-model

This sub-model estimates the influence on sustainability due to the transportation and equipment during different phases of the building project. It accounts for the transportation of raw materials from factories to the construction site. Additionally, transportation within the construction site is computed. The sub-model accounts for the fuel and electricity consumed by various loading, lifting, and concrete equipment used during the building construction phase.

Waste Sub-model

Waste reduction is an essential aspect of sustainability, and hence the framework incorporates the quantification of wastes generated throughout the project's lifecycle. Therefore, the construction-related wastes are accounted for, followed by the general solid waste generated during building operation, and then the demolition waste is computed, thereby accounting for the life-cycle perspective. These wastes are computed on a per unit area basis based on some factors. Sewage generated is also accounted for as a factor of water consumption as per standards. The computing of wastes helps in transforming the same in the form of ecological footprint that represents the pressure on land resources due to waste generation.



The sustainability indicator sub-system considers the impacts of the building sub-system on the environment, society, and economy in the form of various indicators such as various footprints, LCE, the social cost of carbon (SCC), LCC, and jobs computed in their respective sub-models. Hence, the details of the sustainability indicator sub-models are elaborated.

CFP Sub-model

A step function is used in cumulating the rate functions according to the different life cycle phases. It takes inputs from the material, transport, and energy sub-models and computes the total carbon footprint.

WFP Sub-model

This sub-model accounts for the water footprint by quantifying the total water consumption across different building project stages. Hence, the water sub-model feeds directly into this indicator sub-model.

EFP Sub-model

EFP refers to the environmental pressures from the building construction in terms of impact on land resources due to emissions, waste generation, water use, and land use. EFP is computed by taking inputs from the WFP, CFP, and waste sub-models. The ecological footprint is calculated separately for each phase of the project as well as for each component, i.e., Ecological footprint of carbon emissions (EFCO2), Ecological footprint of water (EFwater), Ecological footprint of waste (EFwaste), Ecological footprint of built-land (EFbuilt-land).

LCE Sub-model

This sub-model by taking inputs from the energy sub-model to compute the LCE.

LCC Sub-model

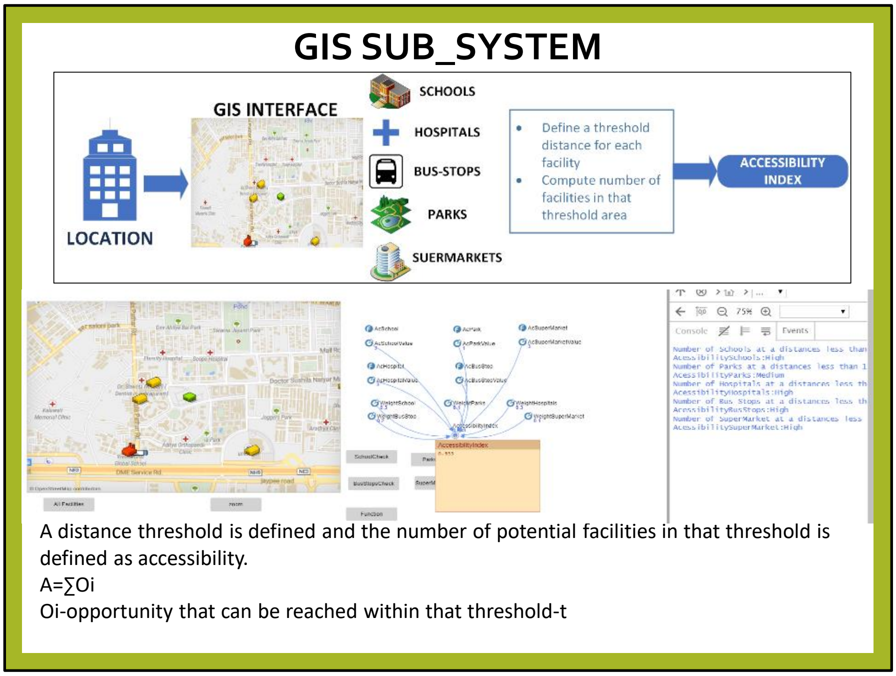
LCC accounts for all the costs incurred in building construction, which is very important from the economic standpoint of decision-making. It takes inputs from the building sub-system on the quantum of material, water, energy, and workers employed.

SCC Sub-model

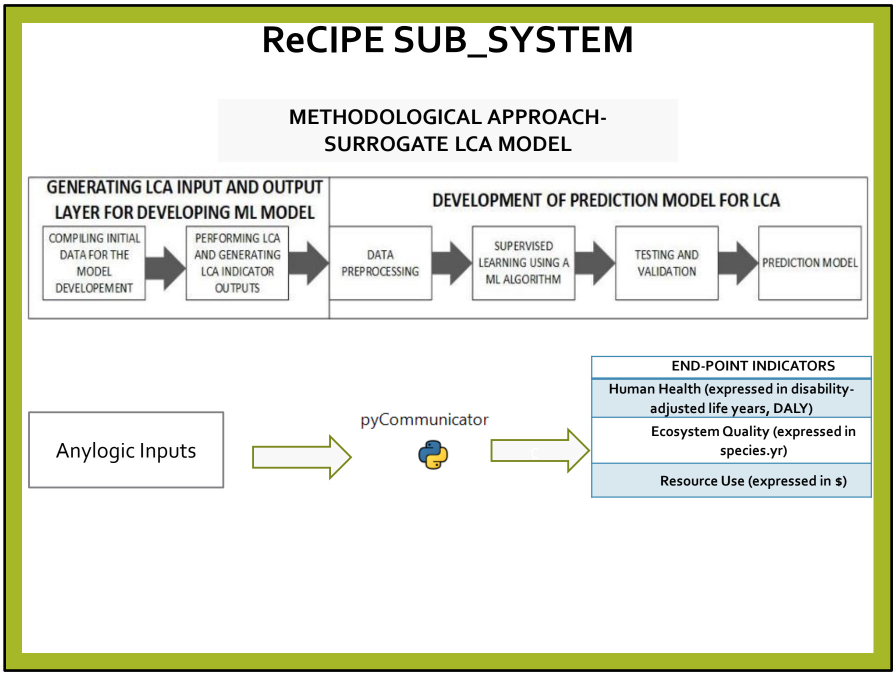
In the framework, the inclusion of the social cost of carbon is an attempt to provide new metrics in economic terms to evaluate sustainability. The SCC sub-model, which expresses environmental challenges related to climate change that result in floods, famines, droughts, cyclones, and biodiversity loss in monetary terms, sheds light on the predicted economic harm.

Jobs Sub-model

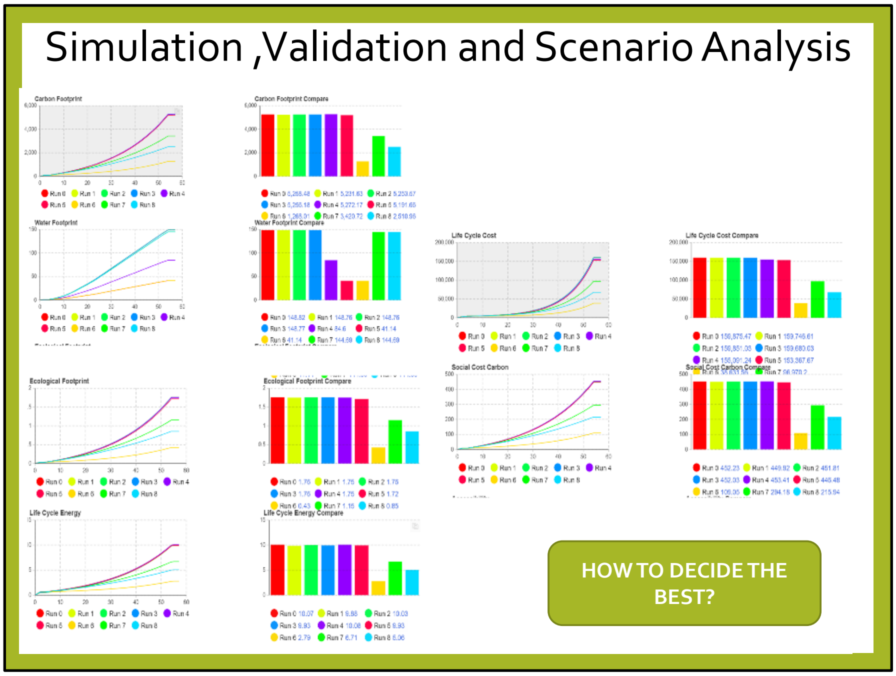
The job-generating potential of construction projects is chosen as a social indicator since construction projects are a significant source of employment. The social indicator of jobs is computed from national reports on employment created per unit area of building construction.



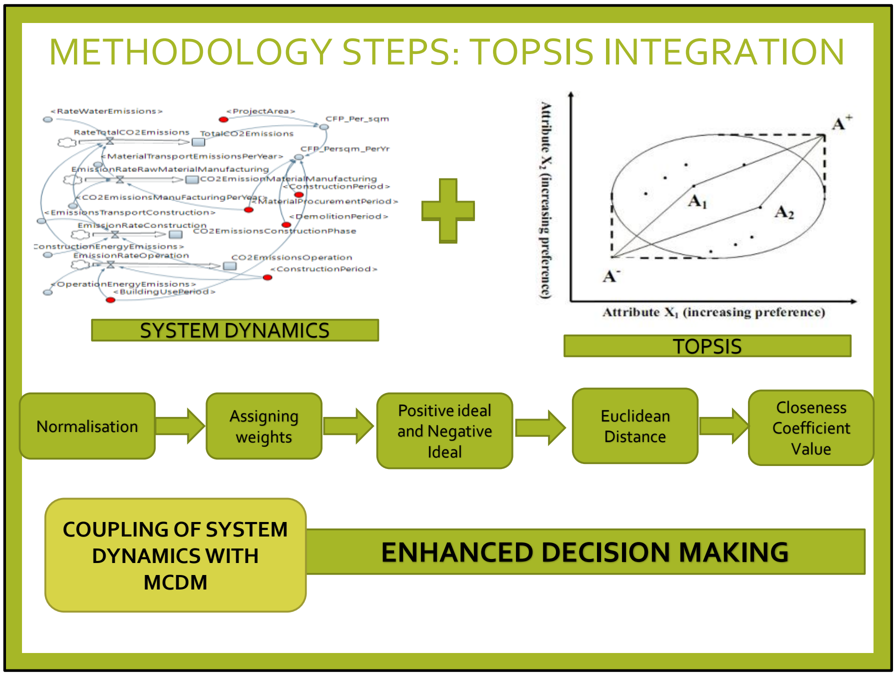
Accessibility is considered as a tool to measure spatial equity. Accessibility to health and social services serve as an important social sustainability indicator. The significant advantage of using it as a sustainability indicator is that it enables consideration of location and equitable access to social facilities. Analyzing accessibility is essential to realize broader sustainability goals, such as reducing emissions by reducing long-distance commuting and promoting low-carbon transport. The cumulative measures method is one of the popular and simplest measures of accessibility. It takes into account both distance and the purpose of the trip. GIS can compute the distances and the number of facilities available in the vicinity of the project under consideration. A distance threshold is defined, and the number of potential facilities in that threshold is defined as accessibility. The Anylogic software has a GIS add-on library that facilitates simulation in a GIS environment. The project's location is input into the framework, which is then identified in the GIS map in the Anylogic interface. The adjoining facilities are generated on the map by coding the proper functions. Then using a Java functions, it is possible to compute the distances and count the facilities within the denoted thresholds to compute the accessibility index, which serves as a social sustainability indicator.



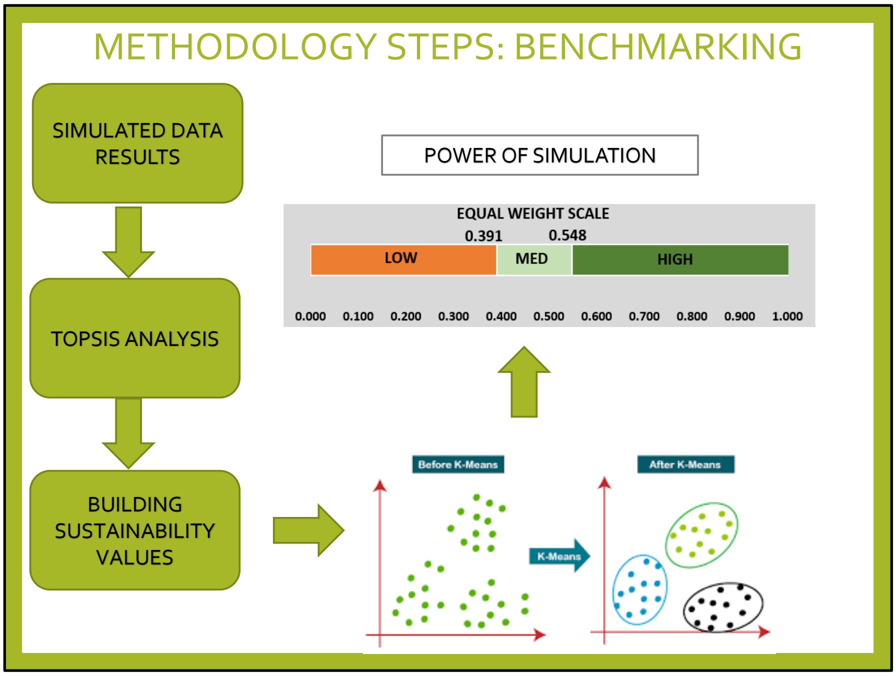
LCA is a critical component of LCSA. However, performing a detailed LCA for buildings and doing various scenario analyses is tedious. to reduce the time, money, and complexity involved in completing LCA on buildings, this research illustrates the potential of multiple regression and ANN tools in developing surrogate models. These models would then assist in facilitating project planning and decision-making. The ReCipe sub-system thus presents a surrogate LCA model, which accounts for the ReCipe indicators, namely ecosystem quality (EQ), resources depletion (RES), and human health (HH), which are commonly used in the LCA impact assessment. The methodological framework for creating such substitute models to carry out LCA of buildings. A training database of thousands of buildings is required to develop such a surrogate model. This database includes the necessary building input parameters and corresponding ReCipe end-point indicators derived using LCA tools such as Simapro (Version 9.3.0.3). Based on the Ecoinvent database, the Recipe Endpoint Method is selected as the impact assessment method to perform LCA (Owsianiak et al. 2014). A suitable machine learning approach in Python is used to analyze the training database. After model testing and validation, it acts as a substitute/surrogate tool to provide the ReCipe indicator values for different input parameters. A Python Communicator (pyCommunicator) developed by Peyman et al. (2021) is used to link the surrogate model developed in python to the AnyLogic software. For any building scenario examined in the AnyLogic interface, the building material sub-model, which accepts user-inputted material quantities, feeds into the surrogate LCA model via this communicator and produces the values of the associated ReCipe endpoint indicators.



It was observed that such a simulation-based approach is capable of numerous scenario simulations yielding different sets of results for each indicator. However, making the best choice among all the criteria is challenging due to many aspects being evaluated. Hence, it was understood that system dynamics could be strengthened further to provide better policy analysis and decision-making if integrated with a suitable decision support system. Thus the framework developed progressed to incorporate MCDM to enable a decision support system for dynamic sustainability-based decision-making of building projects



Even though system dynamics evaluates complex systems and simulates a wide range of scenarios, the multifaceted nature of sustainability needs an efficient decision-making mechanism that could be enhanced using MCDM techniques. Out of several MCDM methods available, TOPSIS was chosen for this study due to its wide application, proven efficiency, and inherent capability to handle good and bad criteria effectively. In TOPSIS, normalization is the initial step that helps compare several indicators with varying measurement units into similar unit metrics. A crucial step in MCDM is assigning suitable weights for the chosen sustainability attributes. Further, suitable weights could be assigned to these indicators based on user preferences. The product of the normalized values and the weights assigned is computed. In the following phase, the most ideal and least ideal solutions are selected from the attribute values for each scenario considered. Determining whether a greater value for an indicator or a lower value is preferable is crucial for this. The next crucial step is to calculate the Euclidean distance between each attribute value and its related PIS and NIS (de Farias Aires and Ferreira 2019). The closeness coefficient (CC) value for each scenario is then calculated by dividing the Euclidean distance from the NIS by the sum of the distances from PIS and NIS for each scenario.



On further investigation, it was realized that TOPSIS, which is used as a means for the decision-making of projects, could also be used to build a sustainability benchmarking strategy. This CC value obtained from the TOPSIS analysis of several building alternatives could be transformed as the Building Sustainability Value (BSV) for each evaluated alternative/scenario. This BSV dataset of CC values could then be used to develop a benchmarking scale. Therefore, following the integration of TOPSIS, a large dataset of buildings of a specific type and functionality is generated. This dataset is fed into the already developed system dynamics interface and simulated to obtain their base case sustainability performance results. The framework is then incorporated with the maximum possible representative set of scenario interventions, which would ideally improve some of the sustainability performance indicators. The buildings in the dataset are thus simulated with these interventions to generate a large set of results across several scenarios. Further, this large dataset of scenario results is fed into the TOPSIS interface in the framework. The resulting BSV dataset obtained from the TOPSIS analysis is then subject to a K-means clustering algorithm which is an unsupervised machine learning algorithm to develop the benchmarking scale. The goal of clustering in this study is to produce a scale that distinguishes between

High (H), Medium (M), and Low (L) sustainability levels using the BSV dataset produced from the TOPSIS analysis of a sizable dataset of buildings and improvement scenarios. This BSV dataset is divided into three distinct clusters by K-means, and the boundary values for each cluster are then determined. This is done by inputting the CC values obtained through simulation and TOPSIS analysis into a python program that performs the clustering and generates distinct values, which divide the whole dataset into three parts.

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