Using a system dynamics framework to develop a decision-making model for Building Energy Efficiency Codes in the Global South

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Abstract

Building energy efficiency codes (BEECs) remains the basis for optimised and contextualised building simulation. Thus, the lack of BEECs in 28 out of the identified 57 Global South (GS) countries hinders the optimisation of building design and simulation in the GS. This paper uses a system dynamics (SD) approach to develop and present a framework to structure and compare BEECs. The synthesis of the structure of Global North (GN) models with the determined hierarchy of built elements in the mandatory BEECs of 19 GS countries results in a proposed GS model. Ultimately, the resulting model is applied to develop a Sustainable Levels Indicators Matrix, Model and Maps (SLIM^3) as an interactive online decision-making tool.

Keywords: *System dynamics approach; Building energy efficiency codes; Building simulation; SLIM^3; Global South; Climate change*.

Key Innovations

- A comprehensive review of Building Energy Efficiency Codes (BEECs) to identify the hierarchy of built elements.
- Preparing a consolidated database of current BEECs practices in the Global South (GS).
- Developing a framework and decision-making tool for simulation practitioners, facilitating progress in optimising building design and operation, including affordable simulations in the GS region.
- Addressing the United Nations' Sustainable Development Goal (UN SDG) 13 (Climate Action) and UN SDG 11 (Sustainable Cities and Communities) through a BEECs decision-making framework for the GS.

Practical Implications

The lack of BEECs in GS countries contributes to many built environment developments not addressing the SDGs of the UN. It further leads to the near absence of building simulation within the GS. A decision-making model for BEECs in the GS is necessary to perform building simulations. An SD framework that uses building element hierarchies is the first stage of developing an online database and decision-making model to address the identified need in the built environment of the GS.

Introduction

Global warming holds significant threats to the entire planet, but GS countries are more vulnerable to the risks associated with climate change (Anguelovski et al., 2014). Some contributing factors include population growth, rapid urbanisation and increased natural disasters. These aspects have a direct impact on the future expansion of the GS built environment. At the same time, many GS countries lack the necessary BEECs (Gaum & Laubscher, 2021).

According to the South African Cities Network (SACN) (2009), *"[t]here is a direct link between buildings and climate change due to the high rate of carbon emissions from the construction and ongoing use of buildings"*.

In 2019, total CO_2 emissions from the building sector reached their highest levels (International Energy Agency (IEA), 2021). It is unlikely that the built environment will meet future climate change targets while fulfilling the potential goals of the Paris Agreement.

The Paris Agreement uses a five-year review cycle to review the progress on meeting agreed targets. In the last review, 38 countries included BEECs and 53 mentioned building energy efficiency (United Nations Environment Programme (UNEP), 2020). These reports are predominantly from high-income or developed countries.

It is necessary to decarbonise the built environment globally by adopting more precise, more stringent, compulsory policy pathways. However, the GS is struggling to fulfil this real-world need. In addition, the region's lack of BEECs exacerbates the challenge of adopting building simulation and optimisation tools. A system dynamics framework could inform the development of a decision-making model focusing on BEECs in the GS. The purpose of such a decision-making model should be to assist countries without applicable regulatory codes to develop an incremental implementation framework.

While international best practices should inform a bespoke GS model, it must be an extension of successful GS practices that already address the contextual challenges while incorporating sustainable level indicators and guidelines to address the impacts of climate change on their built environments.

Methodology

Structure of the paper

The following section of the paper first evaluates the GN and GS models using SD to assess regulatory codes in the built environment. Secondly, it amalgamates the GN and GS models. Thirdly, it proposes a hierarchical strategy to evaluate and inform the development of BEECs in the GS. Lastly, the consolidated SD framework based on building element hierarchies is used to develop an online database and decision-making model to address the identified need in the built environment of the GS.

System Dynamics

The SD approach uses a combination of theories, methods, and philosophies to investigate system behaviour in various environments. It can be used in business management, engineering, and environmental change. SD methodology provides a framework to analyse the influences between actions and reactions while exploring how and why elements and processes in a system change. It leads to understanding how a system works and assists in predicting how situations might develop over time (Forrester, 1991). A summary of the SD relationship's structure, elements and components is presented in Figure 1.

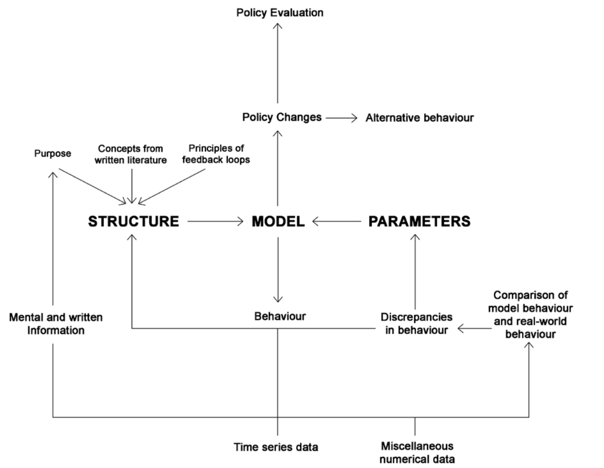

Figure 1: Summary of the elemental flow process of SD (Manage, 2021).

GN models

The analysis of the GN model is based on two frameworks from varying periods. The first model was developed by Sheridan et al. (2003), while the second is known as the Nordic Five-Level Model, dating from 1978.

A systematic review of the Sheridan *et al.* and Nordic frameworks was conducted to identify the classification methods implemented and the structure of regulations.

GS models

The comparative study for the GS region focused on 19 countries with mandatory BEECs for the entire sector. A different approach was required to formulate a new framework to compare the BEECs, identify the structure of the existing compulsory BEECs, and place similar themes into corresponding categories. Thus, a systems approach was developed and is further described as the Hierarchy of Built Elements. This systems approach ensures that parts of a building are placed into various systems, sub-systems and components with specific performance attributes related to one another. The process confirmed the effective synthesis amongst the different code structures while simultaneously enabling accurate comparative analysis of the specific criteria or requirements in all 19 BEECs. Finally, the hierarchy of built elements was divided into five levels and described accordingly.

Comparison of the GS and GN models

The GN models (i.e., the Sheridan, Visscher and Meijer framework and the Nordic model) were compared with the determined hierarchy of built elements for the GS region. This was achieved by juxtaposing the different levels identified in the GN frameworks with the levels of mandatory codes used in the GS.

The SD analysis used the primary sources, headings, sub-headings, and secondary sub-headings. Specific criteria were identified, and the current GS BEECs were categorised accordingly for comparison.

Proposed new GS model

This research product is a proposed GS model titled the Sustainable Levels Indicators Model, Matrix, and Maps ($SLIM^3$). The new GS model was developed from synthesising the hierarchy of built elements, and GN models were used to create an interactive online database. This database is expected to serve as a decision-making framework for GS countries without BEECs.

Discussion

The Brandt line and BEECs in the GS?

Various researchers have highlighted concerns about accurately representing political and economic indicators as a division mechanism. The publication titled *North-South: A Programme for Survival* or the so-called Brandt Report indicates a geographical delineation using a North-South line (Brandt, 1980; Vanolo, 2010). This report gave rise to the Brandt Line, which served as the contemporary delineation between the GN and the GS.

It was essential to revisit the Brandt line by consolidating typical definitions and descriptions of the GS. The terminology includes countries showing poor economic growth referred to as "third world countries", "less developed countries", "underdeveloped countries", and ultimately, the "Poor South". The result is an updated Brandt line delineating the Global North (GN) and GS as illustrated in Figure 2.

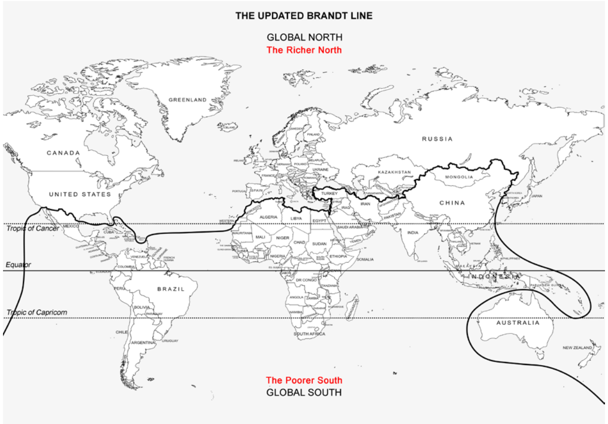

Figure 2: Updated Brandt Line (Gaum, 2022).

The Brandt line and BEECs in the GS

Figure 3 summarises the significant climate change challenges in the built environment of GS countries. The following questions guided the content:

- What are the climatic conditions of the GS countries according to the updated Köppen-Geiger map?
- What are the socio-economic conditions of each GS country?
- Which countries have BEECs or related policies?
- In which sectors of the built environment are these BEECs used?

The spider diagram provided in Figure 2 also indicates the relationships and connections between different GS climate change challenges.

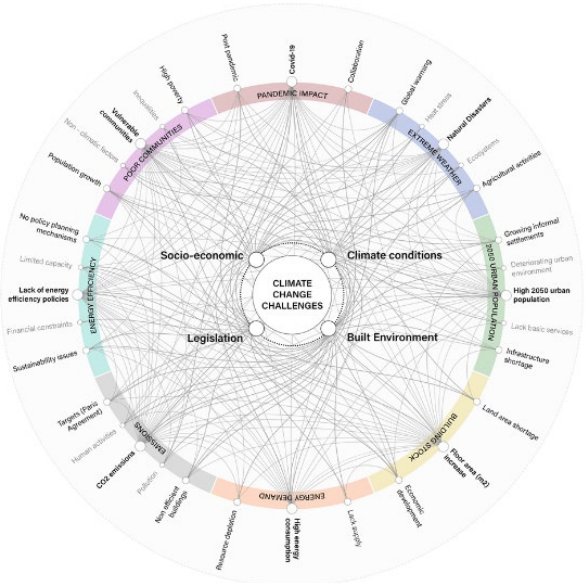

Figure 3: The online database highlighting GS climate change challenges (Gaum, 2022).

The status of BEECs in GS countries (as defined by the updated Brandt Line) is presented in Figure 4. A review of the BEECs for 57 GS countries indicated that only 19 countries have mandatory regulations covering all their building sectors.

The 19 countries are Algeria, Bangladesh, China, Colombia, Egypt, Ghana, Iran, Kuwait, Malaysia, Mexico, Morocco, Nigeria, Pakistan, Qatar, Saudi Arabia, Singapore, South Africa, Turkey, and the United Arab Emirates.

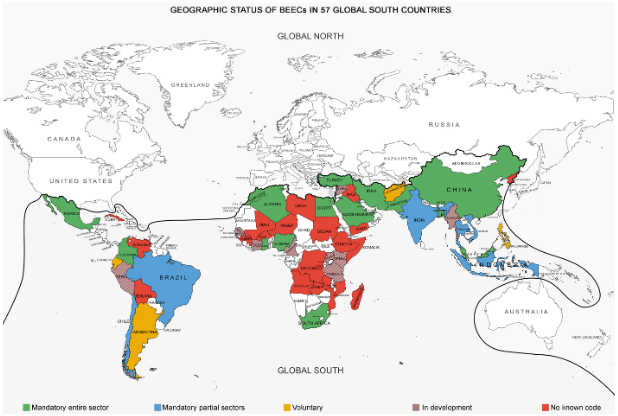

Figure 4: Geographic overview of BEEC status in 57 Global South countries (Gaum, 2022).

Table 1 summarises the identified building sectors with relevant BEECs in the 57 GS countries. It highlights that 28, or approximately 50% of GS countries, are without BEECs, while six countries implement BEECs on certain sections of the built environment and four countries only have voluntary codes.

Table 1: The status and implementation categories of BEECs in the Global South (Gaum, 2022).

No. of GS countries	**Countries with BEECs = 29**			**Countries without BEECs = 28**	
Implementation	Mandatory = 19	Mixed = 10		None = 28	
Sector of the built environment	Entire Sector = 19	Partial Sector = 6	Voluntary = 4	In development = 9	No known code = 19

Hierarchy of Global North (GN) models

The following part of the paper discusses two approaches to structuring building activities in the GN. The purpose of the discussion is twofold. Firstly, to evaluate their information hierarchy and secondly, to serve as a normative basis for the structural approach and information required from BEECs in the GS.

The following two GN models are studied:

1) The Sheridan, Visscher and Meijer framework
2) The Nordic Five-Level Model

The Sheridan, Visscher and Meijer Model

The study by Sheridan et al. (2003) is the product of evaluating the built environment hierarchy used in Denmark, England (and Wales), France, Germany, Netherlands, Norway and Sweden.

The framework used to structure the comparative analysis of building regulations and codes by Sheridan et al. (2003) consists of three levels: the primary sources and corresponding sections with a description of the various building elements and goals. *Table 2* summarises these components.

Table 2: Structure of BEECs and requirements, adapted from Sheridan et al. (2003).

Levels	Primary sources	Sections	Building element/goal
1	Objectives	Main headings	Fire safety, hygiene, health, energy conservation, accessibility, etc.
2	Strategies	Primary Sub-headings	To achieve objectives (ventilation, thermal insulation, etc.).
3	Parts of buildings	Secondary sub-headings/ Criteria	Elements of construction (walls, floors, ceilings, roofs) and areas in the building (circulation routes, habitable areas, etc.).

Sheridan et al. (2003) also include sub-sections specific to building typologies and climatic regions.

The Nordic Five-Level Model

The Nordic Five-Level Model is a widely adopted method used to organise the various headings, sub-headings, and themes of BEECs. In 1978, the Nordic Committee on Building Regulations (Nordiska kommittén för byggnadsbestämmelser, NKB) developed the structure for building regulations to clarify and harmonise the approach between functional requirements, prescriptive-based codes and building performance regulations (NKB, 1978).

The Nordic Model initially used a five-level pyramid, outlining the hierarchy of built elements and the general structure of building regulations. The pyramid structure was fundamental during the development of regulations in Scandinavia and other European countries (Foliente, 2000; Meacham et al., 2005; Meacham, 2016). The Nordic Model and its approach are also widely used in the United States.

The first two levels of the Nordic model provide the overarching objectives and functional statements of a building and the building components. The third level offers operative performance requirements using quantitative criteria of specific building elements to develop the hierarchical framework.

In certain instances, the original Nordic Five-Level Model has been adapted to a four-level pyramid, with the lowest level addressing appropriate solutions and compliance methods recognising deemed-to-satisfy regulations that prescribe mandatory requirements. This is mainly because prescriptive solutions are just one of several potential methods for verifying compliance, including those expressed under the performance solutions (testing, application of well-established engineering principles and mixed method) (Foliente et al., 1998).

The South African National Building Regulations (SANS 10400) were placed alongside the Nordic model to test its possible use in the GS. Figure 5 combines the Nordic model and provides an overview of the various levels, headings, and associated descriptions.

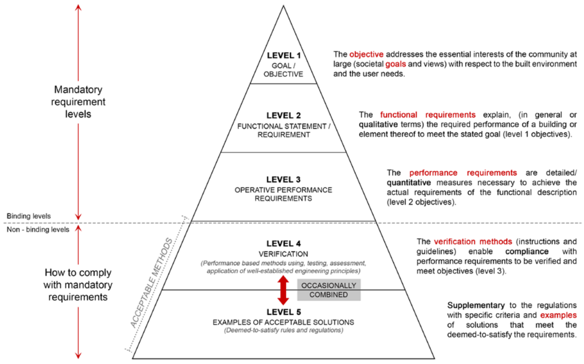

Figure 5: Nordic five-level hierarchy structure for performance-based codes (Adapted from South African Bureau of Standards (SABS) (2010))

In line with the SD framework, the models contain corresponding headings, sub-headings, and terminologies. Also, the respective definitions can be substituted or used interchangeably with little to no information loss. The results of the SD comparison highlight the similarities and indicate how the GN models could be successfully used in the GS.

Comparing mandatory codes in the GS

The SD approach emphasises the need for a BEECs hierarchy of built elements that responds to the contextual challenges of the GS. The SD framework could ensure harmonisation between different GS code structures. Therefore, parts of a building are placed into various systems, sub-systems, and components. The relationship level of specific performance attributes requires scientific weighting between the different building elements.

The first stage reviewed the building and building performance requirements (Level 1: the overall goal). The second stage divided the building into various generic systems (Level 2: Objectives). The third stage divided generic strategies into multiple sub-systems (Level 3: Function). Subsequently, the individual building components must be identified (Level 4: Individual building components). Finally, each building component's performance requirement must be quantified (Level 5: Performance or energy efficiency criteria). The final stage identifies precedents and appropriate examples applicable specifically to the GS (Level 6: Solutions and Examples), as illustrated in Figure 6.

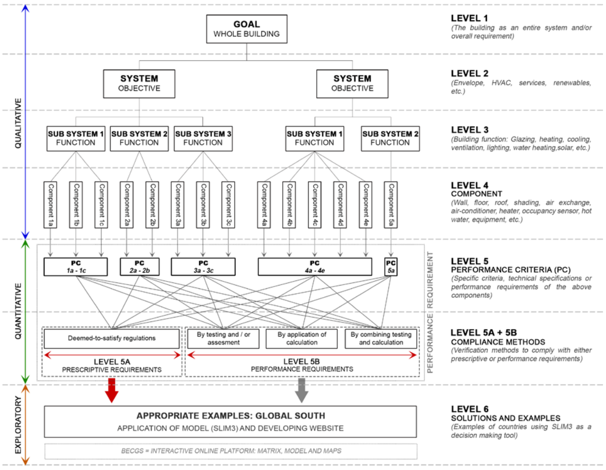

Figure 6: The structure of building codes in the Global South model (Gaum, 2022).

Comparison of the GS and GN models

This part discusses the comparative analysis of the regional models, informing a proposed GS model. Herewith is an overview of all three approaches and the various integration levels. In addition, it focuses on the structure, scope, and technical specifications of all 19 GS countries' BEECs. The Nordic Model developed and articulated the basic structure, and the Sheridan, Visscher and Meijer framework was applied. Still, it applies equally to the Systems Approach (hierarchy of built elements) developed in this paper. Furthermore, the structure and scope of BEECs and the identified attributes (terminologies) from all three methods are organised into corresponding levels, as shown in Figure 7.

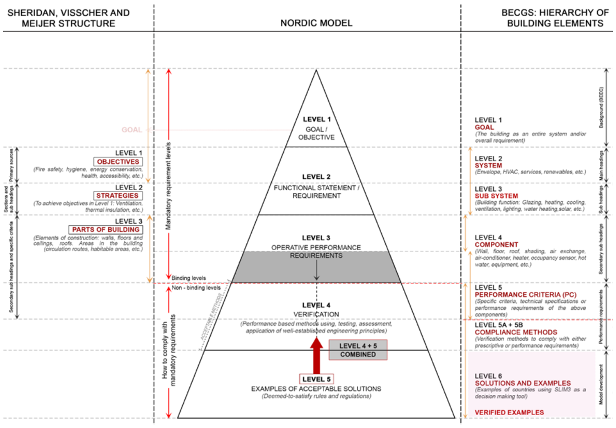

Figure 7: Comparative summary of all three approaches (framework from Sheridan, Visscher and Meijer, Nordic Model and Hierarchy of Built Elements) (Gaum, 2022).

The results highlight the different terminologies identified across all three frameworks. The Sheridan, Visscher and Meijer terms are underlined and placed in parentheses, Nordic Model terms are *italicised* and placed in parentheses, and the Systems approach terms are written in **bold**. The synthesised steps for structuring codes are described as follows:

- Step 1: Formulate an overarching **goal** or (*objective*) at the apex level. This will be the whole building or purpose for regulating energy performance in buildings.
- Step 2: Delineate one or more **systems** (*functional statements*) (objectives) for the goal. When a system relates to a building element at a lower level, the functional statement should be developed at the appropriate level.
- Step 3: Delineate one or more **sub-systems** (*functional requirements*) (strategies) for the preceding systems. In cases where a sub-system relates to a building element at a lower level, the functional need or strategy should be developed at that level.
- Step 4: Delineate one or more **components** or parts of a building (*operative performance requirements*) from the systems or sub-systems in the preceding hierarchical levels. This stage necessitates qualitative descriptions and deemed-to-satisfy prescriptive requirements for which a lower level is essential to support this.
- Step 5: Delineate one or more **performance criteria** (*operative performance requirements*). This stage necessitates quantitative elements that support the higher-level objectives. In this case, those quantitative elements are not provided, proceed to the next hierarchical level, and restart by delineating the components.
- Step 6: Delineate the **methods for compliance** (*verification and acceptable methods*) for each respective measure. Compliance approaches should be buoyed by a minimum of one valid evaluation method. This can either be the prescriptive requirement route or the performance-based route.
- Step 7: End the procedure at the highest level of the hierarchy, where a complete **solution** (Objective, Criteria, Evaluation, Commentary) can be identified.

The steps mentioned above were synthesised to form the basis for developing the proposed GS model and, ultimately, the SLIM^3 decision-making framework. Thus, the study progresses to provide appropriate solutions and examples using the 19 GS countries as a case study.

Proposed GS model

As previously stated, the foundation of this model originates from established GN models and the hierarchy of built elements in the 19 mandatory BEECs from the selected GS countries. These three concepts are illustrated in Figure 8 as one comprehensive framework for structuring and employing a genuine structured approach. The proposed GS model can be divided into two categories, qualitative data, and quantitative data. The benefit of this description is two-fold. Firstly, it allows for identifying patterns and similarities between the existing 19 BEECs. Secondly, generalisable decision-making principles can be formulated by facilitating effective learning amongst GS countries with and without codes. Ultimately, it can be argued that GS countries learning from one another will yield more applicable guidelines and appropriate policies. The approach enhances the ability of GS countries to develop and implement their BEECs.

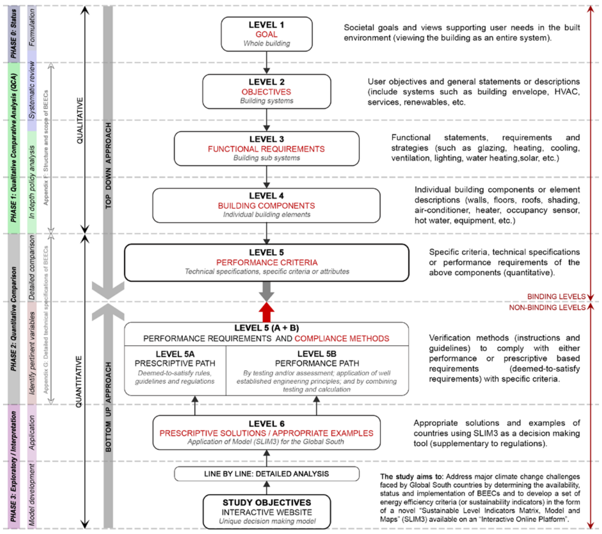

Figure 8: BECGS framework for structuring and comparing BEECs (Gaum, 2022).

The qualitative data (levels 1 – 4) is where the codes' goals, objectives, functions, and components are expressed in descriptive terms. In addition, the qualitative portion sets the structure for the quantitative part of the model (including levels 5 – 6). The quantitative levels are directly linked to the qualitative model levels to enable users to recognise practical examples and accurately align the entire system. Therefore, it allows the platform to support and provide possible data to other GS countries for implementation.

Future SLIM^3

The absence of performance-based requirements means building simulations in the GS are mostly paper exercises with limited real-world value. To address this knowledge gap, Gaum (2022) is developing Sustainable Levels Indicators, Matrix, Models and Maps (SLIM^3) for the GS. An interactive online platform will make SLIM^3 available to built environment professionals, specifically in GS countries. Built environment professionals in the GS can use SLIM^3 as a systematic decision-making tool when performing building simulations.

Although still under development, SLIM^3 will operate on predefined levels with user filters. The first filter will delineate countries based on climatic conditions defined by the Köppen-Geiger climate classification system. This means that platform users can filter their options based on the climate of their desired location. The result will be the identification of GS countries with similar climatic conditions.

The second filter is the hierarchy of built elements and building components. Users can decide on a hierarchical level (i.e., systems, sub-systems, components, etc.) The user's selection on SLIM^3 will identify the GS countries already addressing the selected items. SLIM^3 users can now access detailed quantitative data with specific values. At this point, the SLIM^3 users can determine the data ranges to compare performance values and prescriptive requirements specified by the respective GS countries. The user can now decide whether to use the available values for prescriptive methods or to conduct a building simulation with the available data as a baseline.

SLIM^3 promotes collaboration and learning between GS countries. It can potentially improve strategies aimed at addressing the challenges of climate change in the built environment of the GS through the development of BEECs that are contextually specific.

SLIM^3 is a comparative SD framework using the existing BEECs of the identified 19 GS countries to inform decisions made by other GS countries. The application ranges from individual building level to policy level.

Conclusion

Building simulation offers built environment professionals in the GS region the opportunity to evaluate building performance amidst the region's rapid growth and future development. However, BEECs that form a basis for optimised and contextualised building simulation is lacking in 28 of the selected 57 GS countries. Furthermore, only 19 GS countries have mandatory codes which address all built environment sectors, presenting significant problems and previously identified challenges for the region.

The paper aimed to address this challenge by developing a framework for structuring and comparing BEECs. The resulting framework for the GS was formulated based on the Sheridan et al. (2003) framework and the Nordic Model developed in 1978 (Meacham, 2016). These were categorised as GN models and synthesised with a hierarchy of built elements, resulting from a comprehensive review of the mandatory BEECs applicable to the entire built environment of 19 GS countries. The outcome of the synthesis was a proposed model for GS countries which is being used to finalise SLIM^3 as an interactive online decision-making tool for simulation practitioners and built environment professionals in the GS region.

Formulating a framework for structuring building energy efficiency regulations and developing the online decision-making platform is expected to facilitate significant progress toward optimising building design and operations in the GS. In addition, the platform (currently in progress) can serve as a repository for contextualised building simulation data necessary for accurate predictions and reduced discrepancies. Furthermore, improving GS simulation practitioners' access to contextualised metrics enhances affordable simulations. Within the larger context, the paper and, ultimately, the SLIM^3 platform address the United Nations' Sustainable Development Goal (UN SDG) 13 (Climate Action) and UN SDG 11 (Sustainable Cities and Communities).

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