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Orginal Article

SIMURG: A new model for the integrated assessment of sustainability

Alaattin Kanoglu[1*], Deniz A. Yazicioglu[2], Ozlem Ozcevik[3], Nisa Erkovan[4], Hidayet Softaoglu[5], Burcu Ulker[6], Nazli Varlier[7], Ediz Yazicioglu[8]

[1] Department of Architecture, Faculty of Art, Design and Architecture, Alanya Alaaddin Keykubat University, Kestel Campus, Alanya, Antalya, Turkey;
alaattin.kanoglu@alanya.edu.tr 0000-0002-4917-5309
[2] Department of Architecture, Faculty of Art, Design and Architecture, Alanya Alaaddin Keykubat University, Kestel Campus, Alanya, Antalya, Turkey;
deniz.kanoglu@alanya.edu.tr 0000-0002-5970-5422
[3] Department of Urban and Region Planning, Faculty of Architecture, Istanbul Technical University, Taskisla Campus, Taksim, Istanbul, Turkey;
ozceviko@itu.edu.tr 0000-0002-2312-7122
[4] Department of Architecture, Faculty of Art, Design and Architecture, Alanya Alaaddin Keykubat University, Kestel Campus, Alanya, Antalya, Turkey;
nisa.erkovan@alanya.edu.tr 0000-0002-7473-7131
[5] Department of Architecture, Faculty of Art, Design and Architecture, Alanya Alaaddin Keykubat University, Kestel Campus, Alanya, Antalya, Turkey;
hidayet.softaoglu@alanya.edu.tr 0000-0003-2208-691X
[6] Department of Architecture, Faculty of Architecture, Kirklareli University, Kirklareli, Turkey;
burcuulker@klu.edu.tr 0000-0003-3011-5071
[7] Ph.D. Program of Urban and Region Planning, Graduate School, Istanbul Technical University, Ayazaga Campus, Maslak, Istanbul, Turkey;
varliern@itu.edu.tr 0000-0002-9505-0881
[8] Ph.D. Program of Project and Construction Management, Graduate School, Istanbul Technical University, Ayazaga Campus, Maslak, Istanbul, Turkey;
edizyazicioglu@itu.edu.tr 0000-0002-4724-2758

Abstract: Sustainability assessment is one of the basic issues in the agenda of public authorities and it requires practical tools to measure performance in terms of sustainable development goals. Most studies in literature deal with only one dimension of the problem of environmental components of sustainability. These studies discuss entities at only one level (cities, buildings, etc.), and one layer (green, smart, etc.) in selected dimensions. The literature includes no models that claim to provide an integrated assessment of entities' performance in the 3D Cartesian system. The presently available models do not offer solutions that would be applicable in practice. SIMURG *(*A performance-based and **S**ustainability-Oriented **I**ntegration **M**odel **U**sing **R**elational database architecture to increase **G**lobal competitiveness of construction industry) proposes using layers and their KPI sets in the assessment process. In addition to philosophical, organisational, integrational, and computational models, this study aims to develop a lean architecture of a relational database model by eliminating ineffective solutions in the practical dimension, i.e. in the computer model. The model can be used by individuals to help them choose built environment whose characteristics match their expectations. Public authorities can utilise the model to increase the level of accountability, transparency, and legitimacy in their decision-making processes.

Keywords: Sustainability Assessment; 3D Cartesian System, Philosophical Model; Frame Model; Organisational Model; Integrational Model; Computational Model; Computer Model

1. Introduction

There are certain difficulties and limitations involved with traditional planning, design, and production processes of the built environment, such as conflict of interests of shareholders, incomplete documentation, lack of coordination among the organisations at different phases of the production process, lack of control in the construction phase, etc. For this reason, there may be issues related to the results of this processes. While the clients/entrepreneurs are taking all the critical decisions to increase their profits, the end-users, especially in developing countries, feel aggrieved for various reasons such as inadequate codes and regulations, lack of information about standard performances that must be provided by products, defective mechanisms that are supposed to protect the society. Moreover, economic losses on a national and global scales occur, limited resources are wasted, and difficulties related to sustainable development process increase. Therefore, this process must be re-thought and replaced by alternative approaches, particularly with the support of computer-based tools, in order to increase transparency and accountability of decision-making processes, primarily in developing countries.

There are numerous studies in the “sustainability” area which are concerned with the “analysis” part of assessment-related problems regarding the built environment, but only few remarkable studies tackle the “synthesis” of computational and computer models that are based on a conceptual model with a holistic view. There is a limited number of studies which take a holistic perspective on the nature and components of the problem and attempt to propose an integrated solution that would have interrelated components in both the conceptual and the practical dimension. A comprehensive “systems approach” is essential for effective decision-making regarding global sustainability since industrial, social, and ecological systems are closely linked [1].

Most studies in the literature address only one single dimension of the 3D Cartesian system of sustainability, i.e., the environmental, economic, or social dimension. An exhaustive table which presents the results of a meta-analysis of the studies on the subject can be found in Ulker et al. [2]. Even more examples of papers in this area can be mentioned if we take into consideration those concerning all three environmental dimensions of sustainability in the 3D Cartesian system, and dozens of entities/facts within these dimensions. Yet, it is obvious that these studies are focused on a single or limited number of entities/facts, although defining a comprehensive framework model must be the first step before focusing on specific parts of the whole system.

As for the computation models presented in the related studies in the literature, all models have their computation processes limited by the part of the built environment they are focused on. These models are not comprehensive because in their computations, they fail to consider the interrelationships among the dimensions of the 3D Cartesian system in their integrated assessment of sustainability. Some of the framework models that attempt to solve the problem using such approaches as Life Cycle Assessment (LCA), Life Cycle Inventory Analysis (LCI), and Life Cycle Cost (LCC) are not suitable for the assessment of the social dimension of sustainability. As for the computation process, various studies suggest using a number of methods, such as Multi-Attribute Utility Analysis [3,4], Performance Benchmarking [5-7], Technique for Order Preference by Similarity to Ideal Solution/TOPSIS [8,9], Multi-Criteria Decision Making [10], Machine Learning [11].

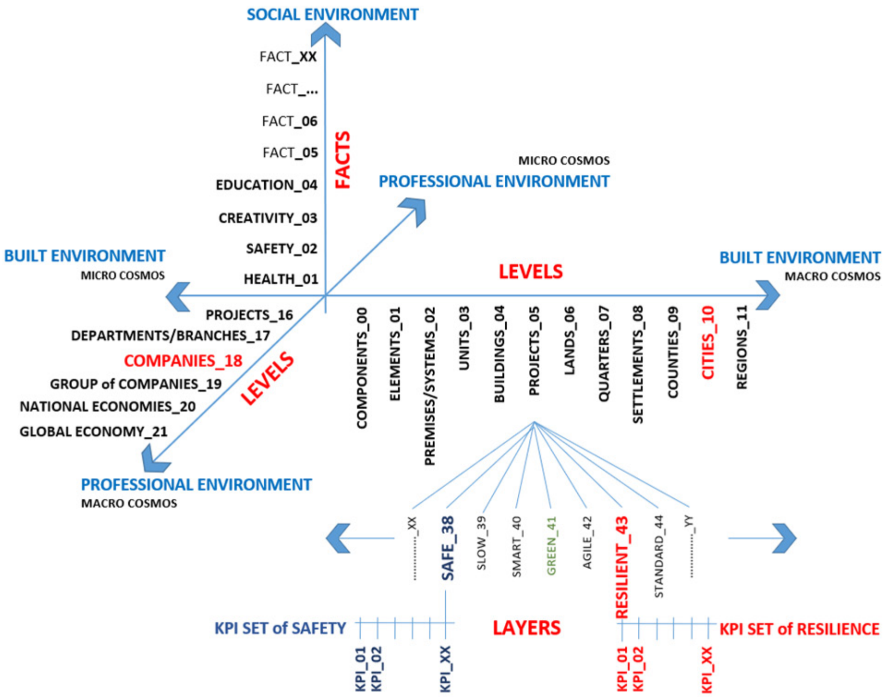

Fig. 1. Generic example of the multi-dimensional, multi-level, multi-layer, and performance-based assessment model of sustainability proposed by the study. *Source: own study*

Examples of related studies in the literature include but are not limited to *a*. built environment dimension [12], *b*. economic environment dimension [13,14], *c*. social environment dimension [15-19]. Similarly, these studies are concerned with only one level in selected dimension such as *a*. product dimension_cities level [16,20,21], *b*. product dimension_buildings level [15,22], *c*. process dimension_companies level [13,14], *d*. process dimension_projects level [23]. Some studies focus on only one layer/label/concept for the assessment of selected entities such as *a*. green [15,24], *b*. smart [16,17,20,21], *c*. resilient [1,25].

None of the above-mentioned studies present a comprehensive approach and thus they do not address organisational or integrational issues in their conceptual models. There are more examples of related studies concerning all environmental dimensions of sustainability in the 3D Cartesian system if we take into consideration those that look at dozens of entities/facts within these dimensions. However, they are focused on a single or limited number of entities/facts and do not discuss the conceptual part of the model or organisational/process-related and integrational sub-models that must be included in it.

2. Research problem statement

As for the studies that adopt a holistic framework and provide comprehensive computational and computer models for the solution of the assessment problem of built environment regarding the sustainability concept, there are few examples in the literature. None of these studies consider the mutual relationships between entities in the dimensions of sustainability in their computational models. Moreover, none of these studies include a practical model that would be the proof of the holistic and comprehensive approach adopted in the conceptual model and show how realistic the proposed model is and what the sources of information are, etc.

Gathering required information is a real problem, since information systems used for this purpose have no standardised structure. Moreover, this information must be organised in a distributed system, and there is no authority that would handle and coordinate these processes. Citizen-based subjective information related to weights and scores for the assessment can be provided by the end-users of the model. Yet, for the objective part of the assessments, official databases of governmental institutions must be reengineered to ensure their interoperability in providing the required information related to entities in the assessment process. Most models in the literature do not address the interoperability issues that explain what the information sources are and how they can be integrated for the assessment of the sustainability of built environment. Therefore, these studies do not provide satisfactory information about the architecture of the models proposed.

Ahmad and Thaheem [26] described a simplified computation model of sustainability in social/economical/ environmental dimensions, which is based on life cycle cost (LCC) and life cycle inventory analysis (LCIA); they used two hypothetical preliminary projects for comparative assessment. Their model places emphasis on "*integration*" based on building information modelling (BIM). In their complementary paper, the authors [27] lay emphasis on BIM and present a comparative analysis of various designs using real estate plugin at the "*cities*" level. Moreover, in their third paper, they propose a conceptual model [28] which aims to make only an economical assessment of the built environment. The last paper of the authors [29] proposes an assessment framework for a "*residential building*" related to social sustainability, by considering the implications of the frame model on BIM. They stress that though their fourth paper intends to emphasise "*social*" sustainability, the overall study addresses all sustainability dimensions [30].

Garau and Pavan [31] and many others use the layer/label/concept "*smart*" in the assessment of built environment entities at "*cities level*" and under the proposed evaluation framework, the quality of life in a given city is evaluated. The authors indicate that a smart city evaluation framework should encompass different "*sectors*", rather than focus on a single one. This study is one of the rare examples that mention the integration of two dimensions of the 3D Cartesian system of sustainability, i.e. the built environment and the economic environment dimensions. Another study conducted by Leach et al. [32] presents a conceptual framework that incorporates an '*intelligent reductionist'* approach to urban policymaking. It comprises four tiers, i.e., lenses, goals, actions, and indicators, derived from the classic strategic planning hierarchy; this framework ensures a holistic approach. The least granular of these four tiers is ‘lens’; there are four lenses, aligned to the four commonly accepted pillars of sustainability: society, environment, economy, and governance.

Elyamany et al. [13] approach this problem at three different levels; *a*. construction industry; *b*. company; and *c*. project; and they propose an integrated mathematical model for the calculation of performance of construction companies regarding these levels. All studies that focus only on specific entities and/or attempt to define/design a framework model certainly contribute to the area and are valuable; however, we need a more comprehensive and holistic approach and a model which would cover almost all aspects of the conceptual dimension and the corresponding components in the practical dimension. Such a model must include proposals for the basic components stated below.

3. The aim and objectives of the study

As a result of the assessments made, it was concluded that the model which would be developed as a solution to the identified problem must include and introduce the components/ sub-models of the solution in the following dimensions (Figure 2):

A. The Conceptual Dimension

- Philosophical/Paradigmatic Model,
- Framework Model,
- Organisational/Process-Related Model,
- Integrational/Interoperability Model,
- Computational/Assessment Model,

B. The Practical Dimension

- Computer/Software Model,
- Implementation Model.

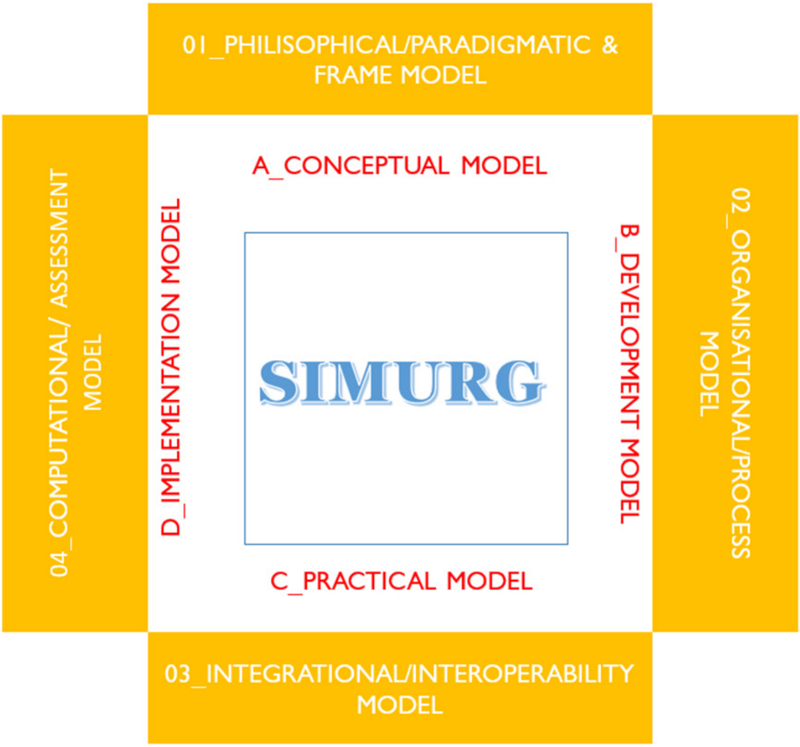

Fig. 2. The components of the conceptual model as the objectives of the SIMURG research. *Source: own study*

SIMURG *(*A performance-based and **S**ustainability-Oriented **I**ntegration **M**odel **U**sing **R**elational database architecture to increase **G**lobal competitiveness of construction industry) is our response to the problem stated above. The name of the model is the title of a Persian tale, which has corresponding versions in Turkish and Western cultures as well. It tells of 30 birds searching for their leader called SIMURG. At the end of their journey, they eventually discover that there is no such bird named SIMURG; however, they are all SIMURG as a whole. The indirect reference to the concept of "governance" in this tale, in the context of built environment, provided one of the basic inspirations for this study. The entities at all scales and levels of the built environment need to use the language of human-centric approaches by placing the governance and sustainability concepts in the centre of all problems and solutions. This paper tries to explain the structure and interrelationships of the models mentioned above.

4. Methodology of the study

Model development studies mostly require iterative processes. Comprehensive models increase the complexity of these processes.

Table 1. Completed sub-Projects of SIMURG and their related Sustainable Development Goals (SDGs)

RELATED SDG	NAME of THE MODEL	DIMENSION	LEVEL	LAYER	DETAILED INFORMATION about THE MODEL
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	SIMURG_ IDEPRO	ECON_ENV	SECTORS	STANDARD	A Model for the Integration of Design and Procurement Processes in Construction Projects: PhD dissertation by Arslan and Kanoglu [33,34].
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	SIMURG_ MORPHO_ BLUE	BUILT_ENV	PREMISES	STANDARD	A Performance-Based Integrated Model at the Building Premises Level for Kitchen Design: R&D project by Yazicioglu and Kanoglu [35-40] for Kelebek-Dogtaş Furniture Systems.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	SIMURG_ COMMON_ _BLUE	BUILT_ENV	PREMISES	STANDARD	A Performance-Based Integrated Model at the Building Premises Level for Bathroom Design: Unpublished MSc thesis by Konuk [41].
11 SUSTAINABLE CITIES AND COMMUNITIES	SIMURG_ CITIES_	BUILT_ENVR	CITIES	CREATIVE	A Performance-Based Integrated Model for Design and Evaluation of Sustainable and Sophisticated Solutions at the City Level for Creativity Layer: PhD dissertation in progress by Varlier, Ozcevik and Kanoglu [42].
11 SUSTAINABLE CITIES AND COMMUNITIES	SIMURG_ CITIES_	BUIILT_ENV	CITIES	MULTI L LYR	A Performance-Based Integrated Model for Design and Evaluation of Sustainable and Sophisticated Solutions at the City Level for Multi-Layer Benchmarking of Cities: PhD dissertation in progress by Ulker, Kanoglu and Ozcevik [43].
8 DECENT WORK AND ECONOMIC GROWTH	SIMURG_ HELMET	ECON_ENVR	COMPANIES	STANDARD	An Integrated Solution for the Departments of Health of Laborers and Safety of Work in Construction and a Model for the Evaluation and Tracking the Performance of Department, MSc thesis by Erdogan [44].

4 QUALITY EDUCATION	SIMURG_ ARCADIA	ECONO_ENV	COMPANIES	STANDARD	A Performance-Based Integrated Relational Database Model for the Assessment Processes of Architectural Design Competitions in Professional Practice and Architectural Design Studios In Academia, MSc thesis by Akturk [45].
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	SIMURG_ CONCRETE	BUILT_ENV	COMPONENTS	STANDARD	A Performance-Based Integrated Model for Design and Evaluation of Sustainable and Sophisticated Solutions at Building Components Level: Unpublished MSc thesis by Serifoglu [46].
8 DECENT WORK AND ECONOMIC GROWTH	SIMURG_ PERISCOPE	ECONO_ENV	DEPARTMNTS	STANDARD	A Performance-based Integrated System for Construction Companies' Procurement Departments Based on the Variations of Estimated and Actual Risks: PhD dissertation by Altindag [47].

Before attempting to develop a framework model, it is necessary to gain a good understanding of the relationships among the components as well as the relationships between each component and the whole system. Thus, in accordance with the draft version of the framework model proposed, components of the system were studied in various research projects, master theses, and PhD dissertations written by the authors (Table 1).

During these studies, lessons learnt from the processes of developing sub-models that are meant to operate within the main system were used for the design of the core part of the model that integrates the components. In this way, a bottom-up approach in an iterative process was adopted and practiced in the development/investigation processes of the relationships between the components and the core part of the model. A comprehensive "systems approach" is essential for effective decision-making regarding global sustainability, since industrial, social, and ecological systems are linked [1].

5. Synthesis of the proposed model

5.1. The philosophical/paradigmatic model

Sustainability is not a concept that is taken into consideration by the corrupted political system, entrepreneurs, or financial institutions, who tend to abuse it, since the built environment is one of the most profitable investment areas in most places of the world. However, the main concept among those that can be achieved by the integrated use of all key concepts for the well-being of society is sustainability. It can be achieved only by matching the basic requirements of life – not only of human beings, but also all living creatures – with their expectations and attributes in an appropriate and balanced way. In our society today, requirements/expectations/identities of citizens fail to be match up with the attributes of built/professional/social environments; i.e. parents persuade their children to enter professions that are supposed to provide high income during their professional lives; individuals invest their financial resources in houses that are only supposed to be highly profitable investments; municipalities support the investments of built environment entities that do not match up with the identities/souls of the cities, etc., and the reason for that is the ill-defined value system imposed on the individuals of the society, especially during the last four decades in Turkey.

5.2. The frame model

A comprehensive and holistic framework model is indispensable to be able to increase the accuracy of the assessment process of the performance of entities not only in the built environment dimension but also in the other two dimensions of the 3D Cartesian system in SIMURG. In order to achieve this goal, researchers have to tackle a trade-off problem between the level of complexity and versatility of the model proposed, and the present study aims to develop a model that can measure/assess/explain the performance of the environmental dimensions of sustainability more accurately and successfully compared with the other models reported in the literature and professional practice. In other words, the comprehensive/complicated character of these models does not guarantee the success of the solution and the "less is more" statement that was one of the popular mottos of the architectural practice in the 1960s must also be considered in the design of the proposed framework model. The current study aims to propose a holistic model that uses "the system approach" to define the relationships between related entities and to design *a*. multi-dimensional, *b*. multi-level, *c*. multi-layer/label architecture to express these relationships among the dimensions of the Cartesian system of sustainability and among the entities on various levels of these dimensions. This approach makes it necessary to analyse the basic components of the system in four main sections: *a*. environmental dimensions of sustainability, *b*. entities on each level of these dimensions, *c*. layers/labels/concepts of assessment of sustainability, *d*. methods/tools of assessment of sustainability. These classifications clarify our perception of the above-stated problem and thus the conceptual model can be interpreted more accurately.

All entities which are located in the 3D Cartesian system of environmental components of sustainability can be assessed by using performance-based assessment approach that applies various sets of Key Performance Indicators (KPIs). These sets are expressed by some well-known terms such as smart, slow, safe, green, resilient, etc., and are referred to as "layers/labels/concepts" in this study. In this context, assessment can be made for a given group of cities by using, for example, the "smart city" KPI set or "safe city" KPI set. The resulting performance values of these both entities at the "*cities level*" will be different at the end of the comparative assessment process depending on the KPI set used. Just like in the case of entities in Product-Related/Physical/Built Environment dimension, i.e., cities in this example, it is possible to make an assessment of entities at, for example the "departments", "companies" or "sectors" levels in the Process-Related/Professional/Economic Environment dimension, and so on. In this way, all companies from the "contractors", "designers", "manufacturers", or "suppliers" categories can be assessed, ranked, and compared internally; just like all industrial segments (sectors) within national economies or all national economies within global economy.

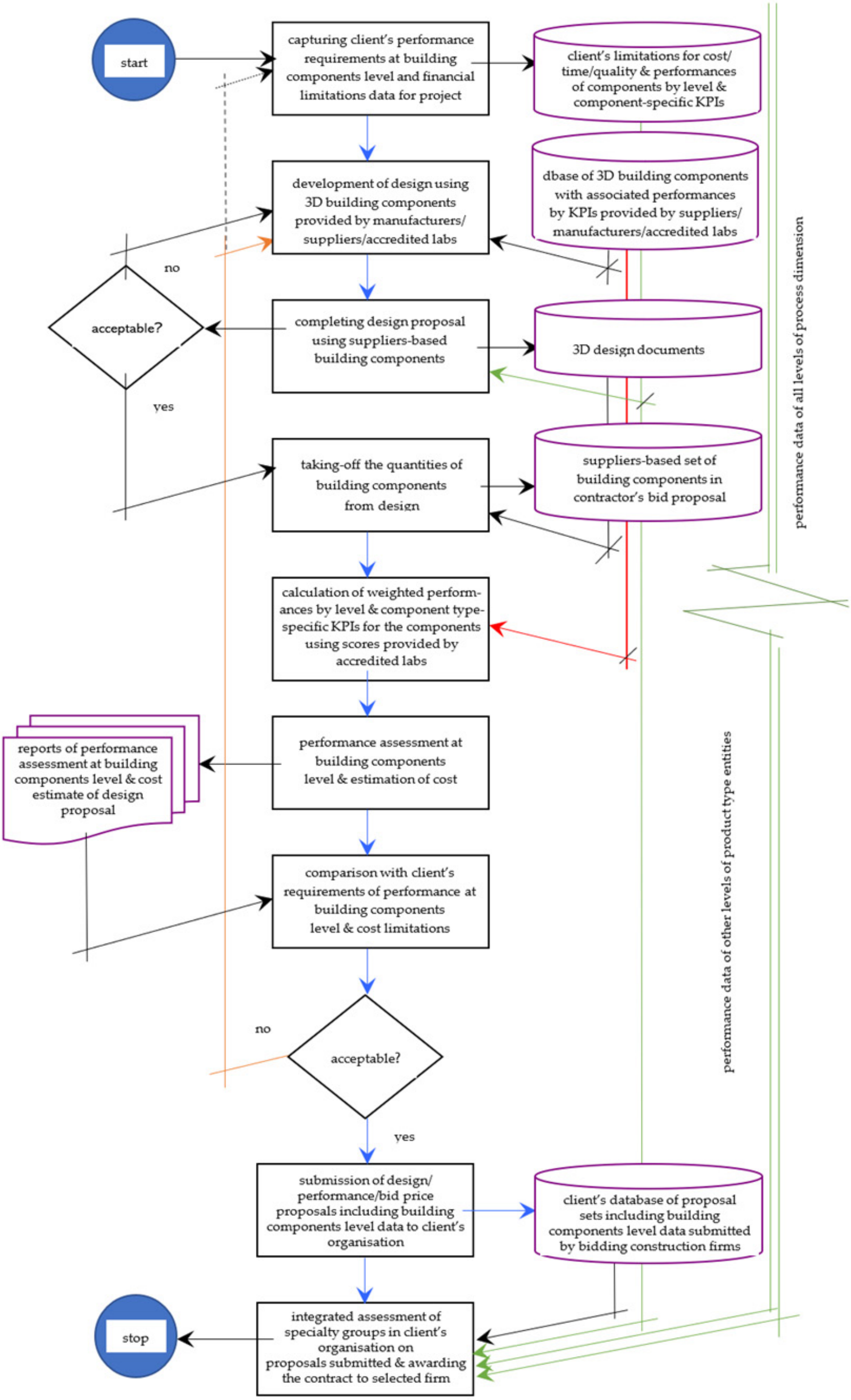

Fig. 3. Sample flowchart of the performance-based assessment for component level objects. *Source: own study*

5.3. The organisational/process model

The performance-based assessment approach suggested in the SIMURG (*A performance-based and **S**ustainability-oriented **I**ntegration **M**odel **U**sing **R**elational database architecture to increase **G**lobal competitiveness of construction industry)* project entails using the services of accredited institutions/laboratories which issue product/process-related certificates for certification-based assessment of entities at all levels of product-related (physical/built), process-related (professional/economic) and human-related (cultural/social) environments. This approach calls for re-thinking the entire production process of the built environment and proposes that a new organisational and process-related model must be developed from scratch. The entities at "01_components of elements" and "02_composite elements" levels must be tested, scored, and certified by accredited labs; the certificates must include the performance values of standardised KPIs of components/elements. The entities at "03_premises of building units" and "04_buildings" levels must be tested by simulation software for the assessment of the acoustical, fire-resistance, earthquake/wind effects, etc., and then scored and certified by design consultancy offices or accredited/authorised governmental or independent institutions, and so on.

These certificates and KPI-based performance values must be attached to 3D models of building components/elements/premises, etc. All design documents must be supported by these certificates and various kinds of evidence, such as physical test results of components/elements or virtual simulation files of acoustical/structural/fire/etc. systems, through the entire approval process performed by governmental offices. This information including 3D objects associated with KPI-based performance values can be qualified as BIM_6D objects.

Flowcharts of performance-based assessment of entities and processes of delivery/production of these entities at various levels of the 3D Cartesian system were developed first for each entity in the dimensions of the 3D Cartesian system. As an example, Figure 3 presents one of these processes related to "01_building components level" entities in the built environment dimension.

Manufacturers of building components/elements/systems must provide BIM_6D models of their products on hosting websites by publishing certificates which include performance values of standard KPIs, so that designers can make a performance-based assessment of their design even at the preliminary design phase by using these components included in their design documents. Thus, it will be possible to receive the performance assessment reports from the model instantly, just like take-off lists or bill of quantity reports. It is possible to locate big data systems with distributed architecture in one single place on the Internet in order to make building components/elements available for designers. Moreover, private/public sector service providers who would retrieve this information from various websites and offer a combined database to the design/construction professionals are likely to appear on the market soon.

5.4. The integrational/interoperability model

5.4.1. Interoperability at the Conceptual Level: The Information Classification Systems

Building Information Modelling (BIM) is one of the significant issues for any model that is designed as a solution to the stated problem. It is one of the primary tools even for modelling historical buildings [48,49]. The performance-based approach will be in the 6D_Sustainability dimension of BIM after the 4D_Time, 5D_Cost dimensions. Interoperability of the product and process-related entities throughout the building production process can be achieved thanks to information classification systems such as OmniClass, MasterFormat, UniFormat, etc.

5.4.2. Interoperability of the Computational Model: The Solar System Simulation

The *Solar System Simulation*, inspired by the interrelationships within our solar system, is essential for the integration/interoperability model and calculation/assessment models of SIMURG. It is presented in Figure 4. It shows the expansion levels of built environment entities in the product-related/physical/built environment dimension; the expansion levels of process-related/professional/economic environment in the process dimension, and a set of social facts in the human-related/cultural/social dimension of the 3D Cartesian system.

All entities at certain levels of environmental dimensions of sustainability in the 3D Cartesian system have their "spherical sizes" that represent the impact factor or "weight" of the entity to be assessed. In other words, the spherical sizes represent the "*mass*", i.e. "*weight"* of the entity to be used in the performance-based assessment of sustainability. As for the "*distance*", it represents the "*scores*" of the factors (KPIs) given by experts or users. The "*force of gravity*" equation provided inspiration for the research team to propose an integrated calculation model. It was modified and converted into SIMURG's computational/assessment model, which takes into consideration mutual interactions among the dimensions of the 3D Cartesian system in the assessment process.

The entity selected for assessment, for instance, can be a specific manufacturer/supplier/designer/contractor company at "02_companies" level if government departments require the calculation of companies' performance in the national construction industry when assessing their eligibility for financial support; or it can be an entity from the "03_departments/branches/dealers" level if construction companies need such calculations for monitoring the performance of their departments and developing corrective policies for these departments which are consistent with companies' strategic priorities.

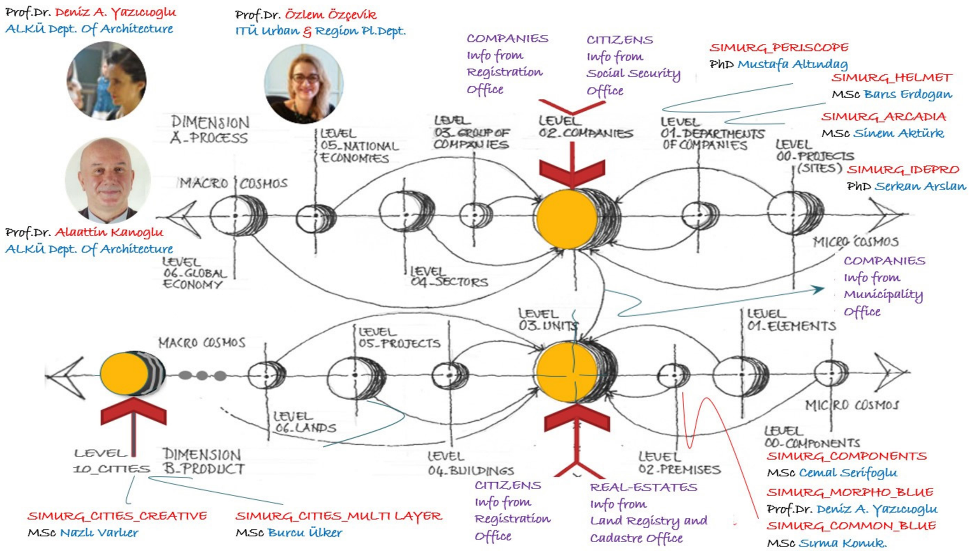

Fig. 4. Solar System Simulation, which is the backbone of SIMURG's integration and calculation models and of the current subprojects matching with various levels of entities of the built environment. *Source: own study*

The master project was designed to include research on and development of related sample models at all hierarchical levels of the performance-based assessment in the above-stated dimensions of the 3D Cartesian system.

As a rule, entities in the product-related/physical-built environment dimension are the essential subjects of assessment. In other words, assessments of entities/facts in other dimensions, i.e., in both the economic and the social dimension, are used to enable a holistic and more accurate assessment considering the effects of these dimensions on the performance of built environment entities. Still, they might be used to make assessments separately within the boundaries of their contexts if, for example, it is a government requirement to compare the performances of groups of companies in construction/textile/mining/etc. industries separately. After determining the entity of the built environment to be assessed, the subsequent step is to select the concept/layer/label for further analysis. The chosen concept, such as green, smart, slow, safe, etc. should be one that matches with the expectations of individuals or institutions in terms of the identity/character of the entity. Each concept/layer has its own set of KPIs including associated impact factors/weights. The scores are supplied by experts and individuals/institutions separately so that both objective and subjective assessments can be included and value systems of individuals in the society can be investigated.

Since the relationship between citizens and the built environment is established at the “03_building units” level by the occupation information recorded in a public database maintained by the government, all the secondary level information such as educational, social, cultural, health-related, crime-related, etc. data related to the citizens recorded by other government offices can be accessed and linked/combined at the desired levels of built environment entities in the model. For example, the arrows in Figure 4, show that entities at various hierarchical levels of the built environment dimension will influence the performance of the selected entity at “03_building units” (apartment/office, etc.). For that reason, the selected entity is located at the end of the arrow. If the entity to be assessed is, for example, at “10_cities” level, all the arrows would indicate this entity. Moreover, the changes in sizes of the spheres (scores) and distances of other entities (weights) to the selected entity require a new calculation process to be added to the computational part of the model.

5.4.3. Interoperability of the Practical Model: Communication with Governmental Databases

The data required by the model can be retrieved by various methods and tools from e.g. governmental databases, surveys, etc. Until now, researchers have used two basic approaches to examine the quality of urban life: the “objective” approach, which is typically confined to analysing and reporting secondary data – usually aggregate data that are mainly available from official government data collections, including the census, at different geographic or spatial scales – and the “subjective” approach, which uses social survey methods to collect primary data at the disaggregate or individual level, and focuses on peoples’ behaviours and assessments, or their qualitative evaluations of different aspects of urban life [31]. Selecting or designing a performance assessment framework and indicators useful for policymaking requires careful consideration; any given framework should be holistic with minimal overlap, be simple, include subjective and objective perspectives as well as quantitative and qualitative data, be usefully organised, and be relevant to decision-making [32].

SIMURG suggests using governmental databases in the "objective" approach; it does not require any other information sources such as surveys since the required "subjective" and individual data will be provided by citizens, who are supposed to subscribe to the service to be able to use the model via their password-protected pre-defined account on the platform. Thus, personal/subjective data will be provided directly by citizens in addition to officially verified individual data organised in the databases of the relevant government departments. Governmental databases are supposed to organise real-time data about all entities and facts related to physical, economic, and social dimensions. Of course, the governments cannot/must not share personal details included in these databases; however, the maps or generalised reports based on the information recorded in these databases should be accessible to citizens/associations/entrepreneurs/institutions, and the entire society to be used in their decision-making processes. Providing equal opportunities to individuals in the society and institutions/companies in the economic segments of the country regarding the accessibility of information is the essential factor of sustainability.

Citizens' residence information is the key factor in the model for combining information from various databases of a distributed network. Built environment entities at "03_units of buildings" level (and also "06_lands" level) are recorded in the Cadastral Information System (TAKBIS: Tapu Kadastro Bilgi Sistemi) database of Cadastral Offices of Turkish governmental departments with their unique real estate IDs, and the associated residential information with the unique Social Security Numbers or IDs of citizens. The quality information about concrete in structural systems of buildings is handled in Electronical Concrete Tracking System (EBIS: Elektronik Beton İzleme Sistemi) database and organised by the related department of the Ministry of Environment and Urbanism, and so on.

On the other hand, while residence information concerning Turkish citizens is recorded in the Civil Registry System (MERNIS: Merkezi Nüfus İdare Sistemi) and the Address-Based Registry System (ADNKS: Adrese Dayalı Nüfus Kayıt Sistemi) databases run by the Office of Civil Register, other records related to various social facts and activities the citizens are involved in are recorded by various governmental units or authorities; e.g. crime information is organised in the National Network of Justice System (UYAP: Ulusal Yargı Portalı) database of the relevant offices Ministry of Justice; information on diseases and treatments of citizens is organised in the Health Information System (E-NABIZ: Elektronik Sağlık Enformasyon Sistemi) database of the relevant offices of Ministry of Health, and so on.

Information related to social/cultural/economic/etc. activities of citizens organised in various databases located in a distributed architecture network can be matched up with built environment entities and by using occupation information about citizens at "03_units of buildings" level of the Solar System Simulation via the unique IDs of citizens. As a result, various "maps" of social facts and activities based on officially verified real-time/accurate data related to various levels of the built environment such as buildings, projects (gated communities), quarters, settlements, counties, and cities can easily be produced. Using these maps may increase the level of precision and accuracy of planning studies and assignment of the required resources; i.e., the right number of medical experts will be assigned to public hospitals by governments, or private hospitals may predict demand for medical supplies, or simply capacities of educational institutions can be identified, etc.

The interoperability of the model provides a challenge that is not related to the ordinary database functions of *combining, grouping, sorting, filtering*, and *customising* data recorded in various databases of governmental offices. The challenge is related to what is not seen at first sight and what is hidden behind the visible relationships. The correlations among various entities, the relationships between dependent and independent variables can be instantly revealed without using statistical analysis software or waiting for experts' analyses; pure logic and professional background of architecture/construction experts are enough to make meaningful assessments by using this powerful tool. Governments are not supposed to share the citizens' details which are recorded in three-tiered architecture databases of governmental offices; however, final reports can be made accessible for all as suggested above.

5.5. The computational/assessment model

"Performance" is a measurable phenomenon. The level of performance is as important as attaining production goals. "What method of measuring performance is used" and "how performance can be increased" have been some of the main topics discussed in recent years by the shareholders of the construction industry, academia, and literature on the construction industry in addition to many other sectors. There are numerous studies and publications in the literature which describe models developed to measure performance at various levels of the environmental dimensions of the 3D Cartesian system of sustainability. Yet, none of these studies and models have proposed an integrated approach to the assessment of sustainability for the various hierarchical levels of built environment dimension by using various sets of KPIs of the layers/labels/concepts selected for assessment. The performance-based assessment approach seems to be the only conceptual tool that provides a common calculation and assessment method that must be placed at the core of computational and integration models. Yet, it requires well-organised management of distributed information systems managed by public and private sector institutions with a novel organisational pattern in addition to a set of equations that is needed for calculating the performance values of the compared entities using their arithmetical scores of sustainability. Examples of calculation models in the literature are limited to entities at certain levels of the built environment, such as building components, buildings, or cities.

The model calculates the total performance of a desired built environment entity using the equations presented below. The entities to be assessed comparatively can be, for instance, a set of building units at the "03_building units" level which are located at various locations/addresses in different cities. Calculations required for the assessment of performances of these building units will be the weighted sum of performance values of each level of the built/physical environment (BE) dimension; yet, this is not enough. Moreover, performance values of the manufacturer/designer/ supplier/constructor/etc. companies which were involved in the production process of these building units must be retrieved from the professional/economic environment (PE) dimension. Finally, the third performance value of social facts in the third dimension of the 3D Cartesian system, that is cultural/social environment (SE) dimension, in total with its associated weight is required for the calculation of the total performance of selected building units. The equations of these weighted performance values of the three environmental dimensions of sustainability are presented below (Equations 1, 2, 3, and 4).

Score of Built Environ. (BE)= Dimension	$\sum_{i=1}^{l} \text{W\_BE}_i \ x \sum_{i=1}^{k} (\text{W\_KPI}_i \ \ x \ \ \text{S\_KPI}_i)$	(1)
l=	Number of hierarchical levels in the built environment (BE) dimension	
W_BE*i*=	Weight of the entity at the level numbered (i*)*	
W_KPI*i*=	Weight of KPI numbered (i) in selected layer given by an expert or user	
S_KPI*i*	The score of KPI numbered (i) in the selected layer given by an expert or user	
k=	Number of KPIs in the layer selected for assessment	
Score of Profess. Envir. (PE)= Dimension	$\sum_{i=1}^{n} \text{W\_PE}_i \ x \sum_{i=1}^{k} (\text{W\_KPI}_i \ \ x \ \ \text{S\_KPI}_i)$	(2)
n=	Number of entities at level (*l*) in (PE) dimension that are involved in the production of (BE) entity	
W_PE*i*=	Weight of the entity numbered (i) involved in the production of (BE) entity	
W_KPI*i*=	Weight of KPI numbered (i) in selected the layer given by an expert or user	
S_KPI*i*	Score of KPI numbered (i) in the selected layer given by an expert or user	
l=	Level of selected entities of the professional environment (PE) dimension to be used in the assessment	
Score of Social Environ. (SE)= Dimension	$\sum_{i=1}^{f} \text{W\_SE}_i \ x \sum_{i=1}^{k} (\text{W\_KPI}_i \ \ x \ \ \text{S\_KPI}_i)$	(3)
f=	Number of facts in the social environment (SE) dimension to be used in the assessment of (BE) entity	
W_SE*i*	Weight of social fact numbered (i) in the (SE) dimension	
W_KPI*i*=	Weight of KPI numbered (i) in the selected layer given by an expert or user	
S_KPI*i*	Score of KPI numbered (i) in the selected layer given by an expert or user	
k=	Number of KPIs in the layer selected for assessment	
Total Score of Built Environ. (BE)= Entity to be Assessed	$\sum_{i=1}^{d} \text{W\_DIM}_i \ \text{x} \ \text{EQ\_DIM}_i$	(4)
d=	Number of dimensions (i.e., BE, PE, SE, etc.) to be used in assessment	
EQ_DIM*i*=	Equation related to dimension numbered (i)	
W_DIM*i*=	Weight of dimension numbered (i)	

In Equation 1, the performances of each level of the built environment are calculated by using a selected KPI set (layer) as well as KPI-specific/level-specific associated weights and scores given by experts and users simultaneously, and thus the first component of calculation is achieved. As it can be seen in the illustration (Figure 4), there is an additional “inter-dimensional” relationship between “Level_02_Companies” in the Process Dimension and “Level_ 03_Building Units” in the Product Dimension, since the performance of entities at all levels of built environment cannot be calculated without considering the effect of performance of companies that takes place in the production process of these built environment entities. Another "inter-dimensional" relationship exists between the facts in the social dimension and built environment entities in the product dimension.

Equation 2 calculates the performance of each entity from the professional environment, for instance the manufacturer/supplier/designer/constructor/etc. companies which were involved in the production process which included the selected building unit. The equation uses a selected KPI set (layer) as well as KPI-specific/level-specific associated weights and scores given by experts and users simultaneously. Thus, the second component of the calculation is obtained. The performance of companies is calculated using performance values of departments/branches/dealers of these companies, such as safety, project procurement, human resources, etc. departments.

In Equation 3, performance of each fact of the social environment is calculated by using a selected KPI set (layer) as well as KPI-specific/fact-specific associated weights and scores given by experts and users simultaneously; and so the third component of the calculation is obtained. The model can be used by various shareholders of the built environment for numerous decision-making processes. For example, citizens may need assessments of building units to choose the most suitable ones to make a profitable investment or find the best one to live in. Similarly, policymakers in a municipality or ministry of construction and built environment may want to know the performance values of their settlements/counties/cities in terms of various KPI sets, such as green, slow, smart, safe, resilient, etc., to be able to determine the concept/layer that yields the highest score, which also means "the identity" of their settlement/county/city, no matter what the level of the built environment is.

Equation 4 represents the calculation of the final score of the entity as the sum of the weighted scores of environmental dimensions of sustainability on the 3D Cartesian system.

The weights of the impacts of entities/facts in all dimensions of sustainability are considered in these equations because of mutual relationships among these entities/facts that are modeled by the assumption referred to as *the Solar System Simulation* (Figure 6), which has already been explained above.

In its computational model, SIMURG proposes using a single layer/label/concept from the list of these layers, i.e. smart, green, safe, resilient, etc., and its KPI set in the calculations and assessment process of performance-based sustainability of any selected entity in the dimensions of the 3D Cartesian system of sustainability. In this approach, it is assumed that citizens select an appropriate label/layer/concept that matches their life paradigms, and they are able to prioritise related KPIs in the selected set by weighing them. This is why benchmarking entities in terms of their performance is based on a selected layer/label/concept.

5.6. The practical/computer/software model

5.6.1. The relational database architecture of the proposed software model

During the ongoing studies on SIMURG, the main result of the project, one of the basic problems to be solved has been the architecture of the relational database model. In the first attempts, built environment entities and certification systems which the performance calculations of entities at the hierarchical levels of the 3D Cartesian system are based on were defined in separate tables. It was found that matching certification data in one table type database object with related entities at various hierarchical levels of the built environment dimension that are defined in their separate hierarchical group tables in this fragmented structure is not a suitable solution regarding relational database logic.

In the second attempt, another architecture was suggested; certification data would be organised in separate table type objects in the database, in tables at two consecutive levels, i.e. information categories common to all entities in the main table and entity-specific particular information regarding relevant entities at various levels of the environmental dimension – in secondary level tables.

Figure 5 presents the lean architecture of the SIMURG relational database, which, however, does not include relationships with public databases of information on social issues such as health, education, crime, etc. yet.

Thus, after six consecutive attempts, we succeeded in overcoming difficulties in placing the related data in various tables of the database and managed to simplify the complicated structure of the relational database architecture of the model, arriving at the final lean solution given in Figure 6. This latest version of the model represents the final architecture including the relationships with public databases with information on social issues as well.

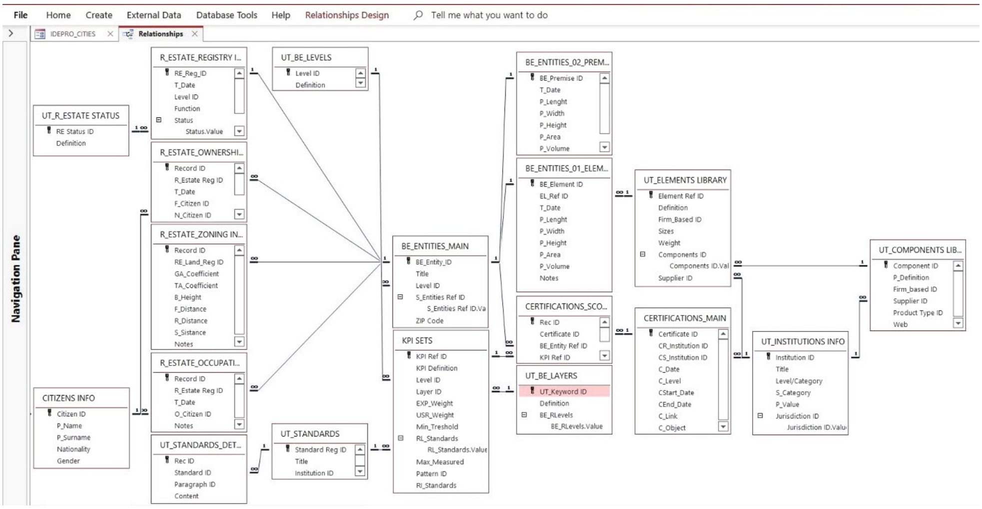

Fig. 5. The final and lean version of relational database architecture of the model without relations hips with public databases with information on social issues. *Source: own study*

5.6.2. The plug-ins of the proposed software model

Sub-projects of SIMURG listed in Table 1 adopt this frame and try to develop and propose an interoperable/functional model to work with it. The start-up screen of SIMURG is presented in Figure 7.

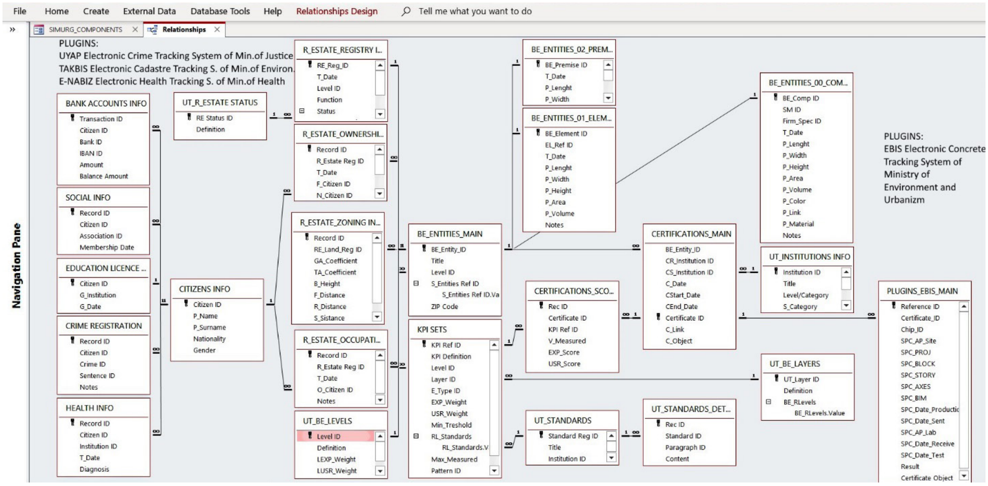

Fig. 6. Interoperability of governmental databases as plugins. *Source: own study*

Since citizens are connected to the built environment at "*03_Building Units Level*" via the MERNIS database maintained by the governmental unit of the Turkish Civil Registration and Citizenship Department of the Ministry of Internal Affairs, it is possible to obtain specific maps with information regarding crime (UYAP database of Turkish Ministry of Justice), health (E-NABIZ database of Turkish Ministry of Health), etc., at the selected level of built environment entities, such as projects, quarters, settlements, counties, or cities.

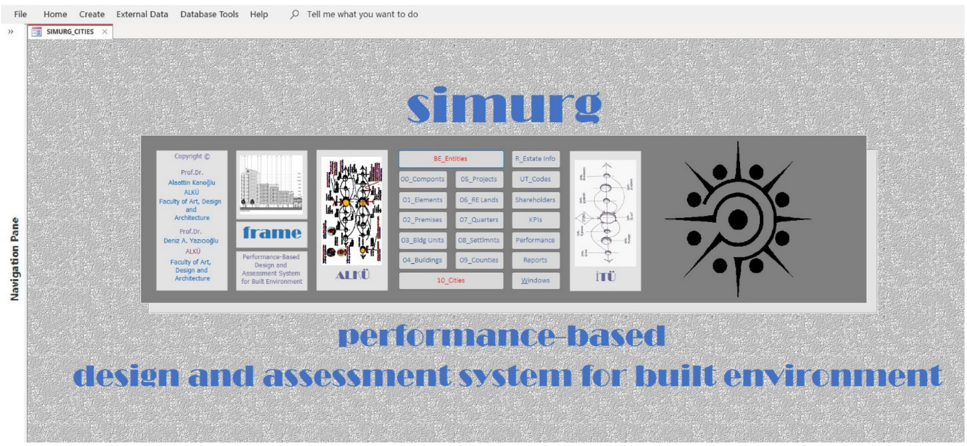

Fig. 7. The user interface of SIMURG software model. *Source: own study*

5.6.3. *The certification system of the proposed software model*

SIMURG proposes a certification-based assessment model. According to this approach, all entities at hierarchical levels of the 3D Cartesian system of sustainability are certified by accredited institutions/labs. The performance values of these entities can be calculated using the KPIs from the provided sets of layers/labels/concepts.

These values are included in the certificates issued by accredited institutions/labs for the analysed entities. In addition to these performance values given by expert institutions, the model requires taking into consideration subjective scores provided by citizens. This data is retrieved directly from citizens who want to use the system to make decisions based on their subjective value system. The session-based approach proposed by the model and the input provided by citizens subscribed to the platform make it possible to obtain a comprehensive set of data on both the objective and the subjective dimension and use it for the assessment of sustainability.

The entities and facts in the dimensions of sustainability can be imported from BIM-based design documents or can be defined manually in the database in a hierarchical structure. Performance-based calculations are made for each entity and fact in these dimensions using expert and user-based scores and weights provided by the certificates issued for company-specific components/elements/premises, etc. by accredited labs/institutions (Figure 8).

The model proposes a novel organisational approach to accreditation given by institutions/labs to entities at various hierarchical levels of the built environment and economic environment dimensions in the 3D Cartesian system. As far as the entities in the built environment dimension of the 3D Cartesian system are concerned, today in various countries certification of building components and elements is mostly limited by standards and norms such as DIN, BS, TSE, etc. In general, these are not performance-based certification systems. There are also other certification systems applied at buildings/projects levels, such as BREAM, LEED, etc. On the other hand, there are some certification processes applied globally in the assessment of professional entities in the economic dimension of the 3D Cartesian system, such as ISO 9000 quality management systems, which also do not provide performance-based certification. The literature that proposes certification of entities/facts at all levels of the built environment and economic/professional environment dimensions of the 3D Cartesian system and uses performance-based assessment does not offer an integrated and comprehensive approach. SIMURG proposes using different sets of KPIs for all entities in each dimension of the Cartesian system in addition to a certification system of these entities at all levels of these dimensions, without an exception. A comprehensive model, SIMURG_MORPHO_BLUE developed as one of the sub-projects of SIMURG by Yazicioglu and Kanoglu [35-40] for the assessment of the architectural design of kitchen premises, can be given as an example of “03_premises” level assessment model. It proposes a certification and accreditation system of premises-level entities in the built environment and also suggests how such a system should be organised.

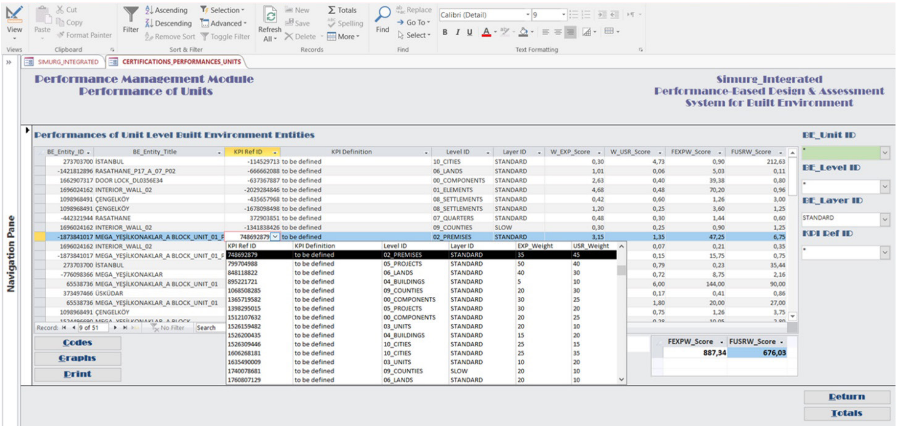

Fig. 8. Certificate-Based Performance Assessment by Expert (objective) and User (subjective) Value Systems. *Source: own study*

The relational database model developed on the MS Access platform proposes a certificate-based scoring approach. This approach currently exists at "00_building components" and "01_building elements" levels of the built environment and it is successfully being applied in some countries. In this approach, all the components and elements produced by manufacturers are registered, tested, and certificated by accredited institutions, such as national standardisation organisations. Some of the gated community projects apply for "green" certificates at "04_buildings" and "05_projects" levels; moreover, some cities have their green, slow, smart, etc. labels certified and declared by relevant authorities. Yet, these assessments are not made according to an integrated approach or model.

5.6.4. The performance-based assessment system of the proposed software model

SIMURG proposes an integrated assessment model that covers not only entire levels of the product-related/built environment (physical) dimension, but also the other two environmental dimensions of sustainability.

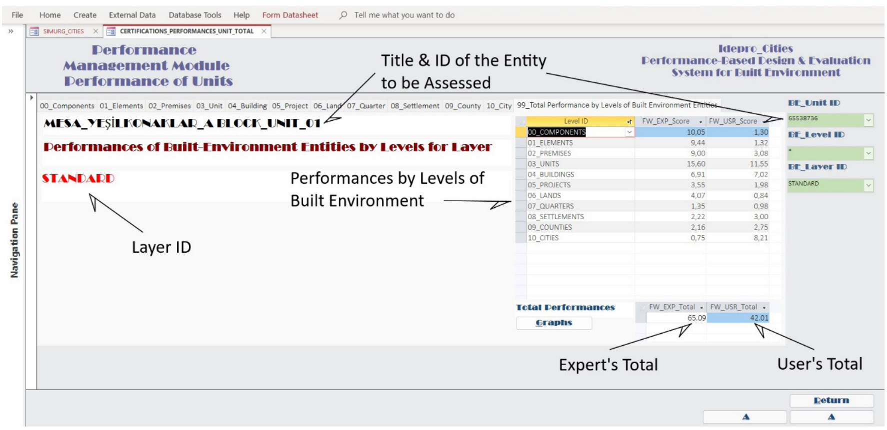

Fig. 9. Calculation of the performance of entities at various levels of the built environment and the total performance. *Source: own study*

As an example, final weighted scores of the entities of each level in the built environment dimension can be seen in Figure 9. These were calculated for a selected entity – an apartment unit, defined by a unique Unit ID of the building in the cadastral system.

Figure 10 represents these performance values in a graphical form. The effects of performance values of the entities in all dimensions are included in tabular and graphical (pie/histogram/radar/etc.) reports that use hypothetical data.

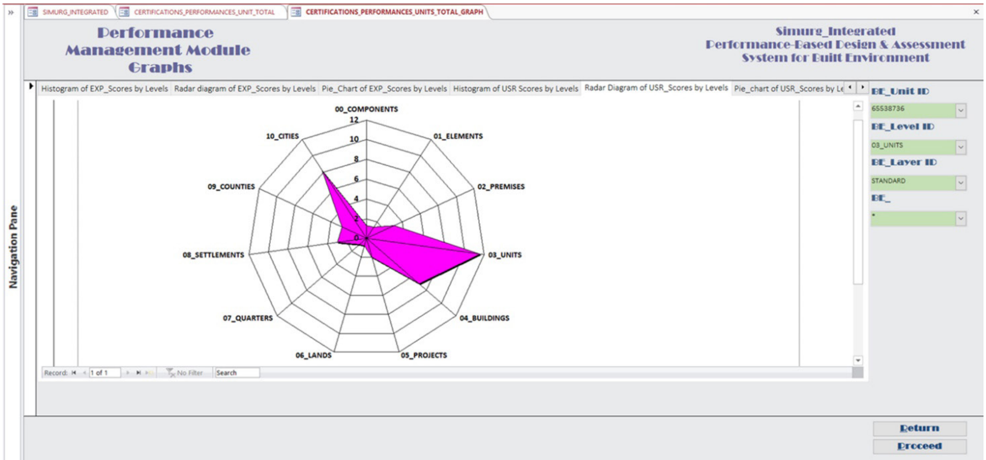

Fig. 10. Sample radar diagram of the components of the total performance of a selected building unit. *Source: own study*

6. Discussion

Sustainability is the key concept in integrating various aspects of life; for this reason, research teams from various disciplines examine this idea in their studies. It is not unusual for these disciplines to define the problem within the boundaries of their domains. Dividing the problem into its smaller components is also one of the basic rules of scientific research and this is why most studies related to the concept of sustainability have their limitations. However, the results of these fragmented studies do not offer a comprehensive perception of the big picture and convenient tools for policy makers to be able to increase the transparency and accountability of their decision-making processes. SIMURG, as the master project that encompasses dozens of potential sub-projects related to entities in all the dimensions of the 3D Cartesian system of sustainability, made it possible for multi-disciplinary teams to cooperate and participate in the conceptualisation phase. Thus, the project proposes a multi-dimensional, multi-level, and multi-layer framework model that covers the whole space of solution to the problem. In addition to civil engineers with expertise in construction management and IT; academicians working in the field of architecture with expertise in construction management, IT, architectural philosophy, architectural history, and conservation; academicians working in the field of interior architecture with experience in designing entities at the building premises level; academicians working in the field of urban and region planning with expertise in sustainability – the whole research team contributed to the design of SIMURG conceptual and practical models.

SIMURG assumes that information required for sustainability assessment has been previously organised in databases of various governmental offices in Turkey and proposes to integrate the fragmented information. Therefore, as a local solution, these Turkish country-specific databases are accepted as external plugins of the SIMURG core conceptual model. This will enable determining the relational database architecture and the relationships of peripheral components. Extending the model from a local to a global scale is the goal to be achieved during the implementation phase and interoperability of country-based systems is necessary to benchmark countries in terms of their performances of sustainability using the 3D Cartesian system.

Dashboards for representing the performance of entities/facts in the dimensions of the 3D Cartesian system of environmental sustainability are developed by international institutions on digital platforms. These solutions are not comprehensive enough and do not support case-based/citizen-centric/multi-part interactive assessment processes for determining the most suitable options that meet the expectations of citizens regarding the professional, social, and built environment. In this paper, SIMURG, which is the most comprehensive model developed for the performance-based assessment of not only entities in the built environment dimension but also entities and facts in the other two dimensions of the 3D Cartesian system, is converted to a practical (software) model. It is obvious that such a model requires the approval of high-level public authorities on both a local and a global scale, and for this reason, the implementation of SIMURG will be a difficult process. Contemporary digital technology is potent enough to manage these comprehensive models and even more complicated ones that would include artificial intelligence functions. A new era called Society 5.0 has just started, supported by digital tools that are currently being made available to fulfil a citizen-centric vision. As soon as the resistance of the construction industry is overcome, we will witness the consequences of these efforts.

7. Conclusions

The paradigmatic model of SIMURG proposes a human-centric governance approach and follows sustainable development goals (SDGs) defined by the UN. The framework model proposes a 3D Cartesian system as a representation of the dimensions of sustainability. The organisational model is based on a distributed system of roles and functions and proposes rethinking these roles and relationships by considering functions of information providers and accredited labs and institutions in the certification process of built environment entities, which covers particular aspects of their design. The integrational/interoperability model proposes integration/interoperability of public information sources. OmniClass information classification system and BIM 6D tools are proposed as means of organising information needed in the built environment dimension. The calculation model is based on a solar system simulation algorithm that is inspired by the gravity equation and performance-based assessment. And finally, the computer model is based on lean relational database architecture that allows the required information sources to be plugged into the frame model.

The master project and its components are currently being conducted in the research lab SIMURG_ALKU & ITU, by both institutions: Alanya Alaaddin Keykubat University (ALKU) and Istanbul Technical University (ITU). The study aims to examine the structure and relationships of an integrated model which will be useful to individuals, institutions, and public authorities operating in the construction sector in making decisions concerning built environment entities. Accordingly, that performance-based approach can be applied in a significant part of industry as a valid and effective approach. Further studies that include all the necessary dimensions of the sustainability assessment problem and address the issue of putting conceptual models into practice are required more than ever.

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