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Integrated Virtual Modeling and Aggregation Framework for Optimized Management of Asphaltic Concrete Mixtures Data

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ABSTRACT

This paper aims to create a model template systematically designed to manage, collate, and transform a plethora of raw asphalt concrete mix design data into a format conducive to simulated modeling. Using a Virtual Lab for simulation modeling is becoming popular in construction and requires data. Also, the gathered raw data in different forms becomes inputted into a well-developed format and framework for ease of usage. The paper achieved its goals by examining relevant literature to identify templates, criteria, principles, and standards for asphalt concrete mix design. Subsequently, it created a template with detailed attention to spreadsheet design and integrating essential parameters and criteria. The text then emphasized simplicity through comprehensive documentation and automating values within each table box using defined criteria. The paper also rigorously verified the template by inputting random asphalt data into the model template to validate the model's accuracy. Results show that the model template can manage physical test data from over a thousand past asphalt mix designs. Outcomes also show that rearranging data in the model produced analogous outputs. Findings from this study may serve as a baseline for those who intend to manage the data collected for asphalt mix design modeling.

1. INTRODUCTION

Simulation modeling in a virtual laboratory involves using available data to simulate certain variables toward achieving specific goals. The simulation process requires data. Other sectors, especially the construction sector, use simulation before physically implementing various engineering systems and procedures [1-8]. From an internet search on Google Scholar, using Virtual Labs or its synonyms for simulation modeling has gained significant attention and usage within the construction and other industries, primarily due to the COVID-19 pandemic. An aspect of construction, namely asphaltic construction, also simulates their asphalt mix design physical testing processes. In parallel, the essential prelude of asphalt concrete mix design before its implementation in construction necessitates meticulous study, mainly focusing on efficiently managing the extensive data acquired for simulating the asphalt concrete mix design testing process through integrated virtual modeling. This need for modeling arises due to the classical nature of the mix problem of many mixes before getting an optimum and re-validation. So, relying heavily on past data-driven analysis that demands the collation, simulation, and efficient management of copious data would assist in tackling the issue of so many mixes. Additionally, it is vital to transform the collected raw data, often available in different forms, into a well-structured and aggregated format within a cohesive framework to aid a seamless simulation.

The data needed for simulation get categorized as input and output, also known in most publications as the “X” and “Y,” respectively. These input data variables are either independent or dependent, whereas the output data depends on these variables for their data [9-11]. Accurate segregation and utilization of these data categories are paramount to avoid delays in simulation caused by improper inputting and collation. Hence, it creates a need to properly know and manage asphalt data during modeling. From the perspective of asphalt mixture design, it is imperative not only to understand and manage data proficiently but also to make it to suit specific regional and local specifications, such as those of Nigeria and other localities [12]. Countries should follow Construction giants of Africa, Asia, China, Europe, Japan, Korea, the UK, the USA, Russia, and the rest who now model their data in line with their specifications. Laws attributed to science, although universal, should be calibrated to the conditions of localities and consider local issues like weather, terrains, and geospatial issues. Considering the local requirements for model development to assist road construction models enhances asphalt mix design models. Recently, countries in Asia have led in construction worldwide and have published works of literature that considered their localities. A model on rutting performance improved its prediction by using suitable and reliable data in line with the Specifications in China for the Design of Highway Asphalt Pavement [13].

Significantly, virtual simulations play essential roles in asphalt road construction, and the key to obtaining a better virtual simulation asphalt concrete mixture design model lies in the availability, collation, management, and usage of numerous data. So, to achieve this study, design, and develop the model, this study has the primary aim, purpose, and objective to create a prototype using a spreadsheet, facilitating seamless raw data input and conversion into a format conducive to virtual simulation modeling.

The rest of this article is organized as follows: Section 2 studies asphalt concrete mixtures. Section 3 presents the analysis of techniques and tools used for modelling properties of asphalt mixes. Section 4 concerns the research methodology, while Section 5 introduces the formulation of the model template. Section 6 presents the integrated virtual modeling framework for optimized management and verification of the model. Section 7 used actual life experiment case data for model simulation and discussions. Finally, section 8 shows the perspectives and conclusion of this paper article.

2. STUDY ON ASPHALT CONCRETE MIXTURES

The construction of roads and other infrastructures requires asphaltic concrete, and those engaged in modeling asphalt need knowledge of using asphalt for road construction. Engineers and road managers concerned with road construction have used asphalt as a cheaper alternative to cement concrete on pavement layers. Studies show that users must meet specific standards in using asphaltic concrete to avoid early failure of the constructed road [14-21]. They listed these criteria as mechanical and volumetric properties mostly. The mechanical properties stated include the strength and pressure requirements. Subsequently, the volumetric properties displayed are the void ratio and bitumen content. Researchers have devised various methods to meet the above criteria, first obtaining an optimum value by testing many asphalt mixes [22]. Second, and for verification, users must remix and retest the best value. Experience has shown that doing these test trials to obtain an optimum value involves almost the same resources and time as verifying it to meet specifications.

The composition of asphalt predominantly comprises aggregates, which constitute a significant percentage of the mixture. It also contributes to a portion of the fillers after undergoing crushing due to traffic load applications. It makes the aggregate an essential component of asphalt. In modelling, considering, understanding, and integrating the properties of these aggregates makes critical meaning because they play a fundamental role in asphalt. Aggregates are primarily used naturally without artificial enhancements, while fillers and bitumen are enhanced. Researchers obtain aggregates from various sources, such as blasted rocks, recycled aggregates, and excavations. They are tested rigorously to ascertain their properties, such as specific gravity, abrasion, crushing value, and others, according to specified methods [23-25]. They also sort these fragments into different shapes and sizes. Testing to know asphalt properties cannot be avoided. Asphalt mixes could use the tested aggregate directly without enhancements. However, from experience, the bitumen can only primarily be used again directly with improvements. During asphalt mixture design, the desired Mineral Filler Content represents the percentage of mineral filler that will meet specifications, typically specified by local standards or project requirements. Also, the total Bitumen Content represents the total bitumen content in the mix as a percentage of the total mix weight. The grading shows the aggregate percentage by weight passing through each sieve size.

Over time, studies modified several asphalt mix design procedures, including but not limited to Superpave, Marshall, Modified Marshall mix, Hveem, and other method standards [26-32]. Some studies also classify asphalt as dense-graded, gap-graded, open-graded, or stone matrix. This study focuses on the Marshall method. The steps developed over time in the Marshall method are to select and determine the type and percentage of aggregate, the grading, size, and properties essential for the design. The next step involves selecting and testing to determine the properties of other materials, such as bitumen, modifiers, and others. The trial specimen mixtures and testing commence afterward in a physical laboratory with varying bitumen contents to calculate the desired properties and choose the most suitable optimum and mix proportion for the asphaltic concrete. Table 1 below shows the grading envelope for binder (base) and wearing courses according to the Nigerian Federal Ministry of Works Specifications. Table 2 below shows compacted asphaltic concrete properties according to the Nigerian Federal Ministry of Works Specifications. Table 3 below shows the aggregate specification for asphaltic base and wearing courses according to the Nigerian Federal Ministry of Works Specifications. Tables 1 to 3 below show a developed concept and information sheet for properties of asphalt.

Table 1. The grading envelope for binder (base) and wearing courses for Nigeria's Federal Ministry of Works

Sieve / Content Sizes (mm)	% By Weight Passing Binder (%)	Wearing (%)
31.8 mm	100	100
25 mm	90 - 100	100
19 mm	70 - 90	100
12.5 mm	55 - 80	85 - 100
9.5 mm	47 - 70	75 - 92
6.4 mm	40 - 60	65 - 82
2.8 mm	27 - 45	50 - 65
1.18 mm	20 - 34	36 - 51
0.6 mm	14 - 27	26 - 40
0.3 mm	8 - 20	18 - 30
0.15 mm	5 - 15	13 - 24
0.075 mm	2 - 7	7 - 14
Bitumen Content%	4.5 - 6.5	5.0 - 8.0

Notes: The% By Weight Passing means the maximum percentage of aggregate materials that passes through different sieve sizes. The wearing layer or course is located on the Binder layer. Also, both Binder and Wearing courses have heights between 40 to 65 millimeters.

Table 2. Compacted asphaltic concrete properties according to the Nigerian Federal Ministry of Works Specifications

Property	Binder (Base)	Wearing
Optimum Bitumen Content	4.5 - 6.5%	5.0 - 8.0%
Stability, not less than	3.5 KN	3.5 KN
Flow	2 - 6 mm	2 - 4 mm
Voids in the total mixture	3 - 8%	3 - 5%
Voids filled with bitumen	65 - 72%	75 - 82%

Table 3. The aggregate specification for asphaltic base and wearing courses according to the Nigerian Federal Ministry of Works Specifications

Pavement Course	Aggregate Crushing Value	Flakiness Index	Absorption Factor
Asphaltic Concrete (Binder)	30	35	0.5
Asphaltic Concrete (Wearing)	30	35	0.5

3. STUDY OF TECHNIQUES AND TOOLS USED FOR MODELLING PROPERTIES OF ASPHALT MIXES

Many researchers developed various physical, mathematical, virtual, machine, or computer models to reduce time, streamline processes, reduce resource wastage, and optimize costs [33-35]. Even though they used physical, mathematical, virtual, or computer models, physical testing models remain essential for validation.

When applied to the asphaltic concrete mix design field or any other field, the mathematical model involves using equations and specific principles to get desired results that still require physical testing [36-41] using the language of mathematics in modelling the failures and properties of asphalt.

The physical model testing method uses the process of real-life experiments and established guidelines to mimic the load and failure activities that could occur on laid asphalt. Various studies used a physical lab for the performance evaluation of asphalt concrete mixes [42-44].

Virtual labs, on the other hand, offer a simulation-rich environment for conducting experiments and learning experiences without the constraints of a physical laboratory [45, 46]. These virtual platforms simulate numerous data to produce desired results, which still require validation through physical testing [47-50]. A virtual, machine, or computer laboratory allows one, in principle, to simulate real-life experiments and activities before they get performed physically. When applied to the asphalt mix design, the virtual, artificial, or computer model simulates numerous data to get desired results that still require physical testing [49-51].

Using spreadsheets as a virtual modeling tool for designing a framework and template becomes interesting. The spreadsheet provides a conducive environment to create tools for simulating, modeling, synergizing, and managing data [52, 53]. Past studies adopted spreadsheets to gather and manage data for analysis based on previous designs [54]. However, a known obstacle in modeling is the need for automated tools for seamless data integration and management [55]. Since spreadsheet modeling needs creativity processes, this paper studied the adoption and use of various stages of designing, building, testing, and analysis from past studies [56]. A further simplification also may result, so this paper looked at the use of concept and information sheet showing the inputs and outputs areas, the primary model and parameter sheet showing the limits, formulas, variables, considerations, and structure, and then the interface sheets showing the combination of all sheets to seamlessly streamline and manage data and the modeling process [57].

Building upon the insights from preceding discussions, this paper endeavors to leverage the potential of virtual labs that use numerous data and specifications tailored to a particular locality to partially replace traditional physical labs for modeling asphalt concrete mix design data, effectively addressing the challenge of an overwhelming number of repeated physical trial mix variations. This knowledge gap emphasizes the necessity to develop a robust framework tailored to specific localities that manage the numerous data necessary for the virtual modelling of asphalt mix designs.

4. RESEARCH METHODOLOGY

The paper achieved its goals and aims using the various methods mentioned. First, it studied various literary works to find templates, criteria, and standards for asphalt mix design. The in-paper review spotted several methodologies, templates, and criteria. The study later selected the Nigerian Federal Ministry of Work's General Specifications for roads and bridges alongside solutions adopted during daily practice as its primary source of information, parameters, and limitations since it is the locality for our data verification source. The paper also used random test results from the asphalt mix.

After, the paper then developed a template that suits our study's aim. It then defined the values in each box in the table for automated results according to the specifications. The paper achieved this by sketching the spreadsheet, organizing it into modules, naming each sheet, starting small, designing, and aligning it to asphalt mix design concepts. Due to its popularity, the paper used the Excel spreadsheet.

Later, the study contemplated many criteria, standards, parameters, assumptions, conditions, variables, and data to ensure that the adopted template best fits the model's purpose. The paper achieved this by keeping it simple, isolating the input parameters, designing for understanding, and documenting essential data and formulas. This paper mainly emphasized wearing because the same process gets repeated for the binder (base) course.

Moreover, the study built, calibrated, and modified the model template to represent the purpose. The paper achieved this by following the usual asphalt mix design plan, making one module row and column at a time, predicting the outcome of each formula, copying and pasting each formula carefully, using relative and absolute addresses to simplify copying, using the Function Wizard to ensure correct syntax, and then using range names to make formulas easy to read.

Subsequently, for verifying, determining, and testing the model's abilities, the study considered the positions and intended values the model should present. In using the spreadsheet worksheet solver, the steps used to do data analysis: first, go to the "DATA" toolbar; second, if you don't have the data analysis tool in the top right corner, please add it from ad ins, however, if you have the data analysis tool, then click on it; third, scroll and select the "regression"; fourth, select the data ranges, for "Y" choose range from S4 down to the end, for "X" select range from "B4" to "N4" down to the end, then click on all boxes apart from residual plots; then choose the box you want your output to appear in then click "OK" or "ENTER". The model template then allowed data input to start and continue to know the template's limits.

Also, the study automated the row with "MIX" using the formulas stated below in Eqs. (1) and (2).

$$X_{MIX} = X_{PRED} \times X_{CF} \tag{1}$$

$$Y_{MIX} = X1_{MIX} + X2_{MIX} + \cdots + X17_{MIX} \tag{2}$$

5. FORMULATION OF THE MODEL TEMPLATE

5.1 Intellectualizing, picturing, and design of framework

Envisage that a model intends to manage thousands of data collected for asphalt mix design data simulation. Various templates, criteria, and standards exist, but one needs to select and use the appropriate ones. Also, such models need extensive data, so they need an aggregated framework template allowing input of numerous data. The spreadsheet, specifically the Excel worksheet, comes into the picture. Most data come in tabular, graphic, word, and number formats. However, the number and word formats can only be simulated, so we need to convert all data. Simulation activities must simulate and model according to the given specifications, so the model chooses or converts the criteria and data to numbers and word format associated with those used specifications.

The worksheet needs automation and calibration, so this study defines the rows and columns and sets limits. Some error data may trickle in, so this paper establishes the worksheet to identify those errors. Basic spreadsheet and data management knowledge is needed to achieve better models.

5.2 Assumptions and conditions

This paper adopted critical assumptions to enable us to modify and formulate the model template and suit this model's goal. The article enumerated them below.

(1) The parameters selected are the most essential ones.

(2) The selected and adjusted only the available sieve sizes within the Nigerian Specifications scope.

(3) Most data should fall within the upper and lower limits of the requirements.

6. THE DEVELOPED INTEGRATED VIRTUAL MODELING FRAMEWORK FOR MANAGING DATA

Table 4 shows the developed primary model template, and it defines each data set as "X" and "Y," symbolizing input and output data sets, respectively. The 'S' data set in the first column represents the sample, specifications (minimum, maximum, or lower and upper limits), and Numbers 1 to ∞ indicate the respective data set rows. These rows delineate the parameters and boundaries considered in the model. The data sets X1 to X13 encompass the crucial input data, serving as independent variables. On the other hand, data sets X14 to X17 constitute supplementary data that enhance the model and are dependent on X1 to X13 during physical testing. However, this step is optional, depending on the user's preferences before virtual modeling. The "Y" data set represents the output data and depends on all the "X" data sets.

Table 4 illustrates the primary model, parameters, and interface sheet, outlining the essential data and information required for asphaltic concrete mix design, focusing specifically on the wearing. It also exhibits the interconnections between each data set. The data sets are denoted as "X" and "Y," representing input and output data.

This section presents a developed integrated framework template designed to streamline, collate, and optimize the management of data collected for better and comprehensive integrated virtual modelling. Table 4 below shows a developed primary model, parameter, and interface sheet showing the data and information needed during asphaltic concrete mix design for only wearing. Table 4 below defined each data set as "X" and "Y," representing the input and output data sets. The S data set for the first column shows the sample, specifications (minimum and maximum or lower and upper limits), and Numbers 1 to ∞, representing the data set in those rows. The rows represent the parameters and limits of the model considered in the model. The data sets X1 to X13 represent the most needed data input and are our independent variables. The data sets X14 to X17 represent extra data that aids in making the model better, and they depend on the data sets X1 to X13 during physical testing. However, the process often gets skipped depending on the user’s choice before virtual modeling. The data set "Y" represents the output data, and they depend on all the " X " data sets. Table 4 below also shows the interface between each data as described in the row with "MIX." The box with “YMIX" is the value that the entire data set will predict. All the data sets get filled during virtual modeling except for the box with "YMIX." So, to manage data sets better, users would get past asphalt mix design data and fill rows numbered one to infinity with data. Next, users would generate mathematical coefficients using the data sets in rows numbered from one to infinity. Later, the data set in a row named "PRED" between X1PRED and X17PRED gets values inserted, and then the virtual modelling takes place to predict the “YMIX” before testing it in a physical lab to verify and validate.

Table 4. Developed primary model, parameter, and interface sheet for managing asphalt mix design data

Sample (S)	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	Y
MIN	100	100	100	85	75	65	50	50	36	26	18	13	7	7	0	0	0	5
MAX	100	100	100	100	92	82	74	65	51	40	30	24	14	14	30	35	0.5	8
1																		Y1
2																		Y2
∞																		Y∞
CF																		
PRED																		
MIX																		YMIX

Notes: 1. The sample data set of X1, X2, X3, X4, X5, X6, X7, X8, X9, X10, X11, X12, X13 represent the sieve sizes of 37.5 / 31.8 mm, 25 mm, 19 mm, 12.5 mm, 9.5 mm, 6.4 / 6.3 mm, 4.75 / 2.8 mm, 2.36 mm, 1.25 / 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and 0.075 mm respectively while X14, X15, X16, X17, and Y represent the Filler (%), Aggregate Crushing Value (%), Aggregate Flakiness Index (%), Aggregate Absorption factor (%), and Bitumen Content (%) respectively. The CF represents the coefficients. The PRED represents the X data set only for prediction. The Y1 to Y∞ represents the observed Y.

7. USE OF RANDOM CASE FOR VIRTUAL MODEL SIMULATION AND DISCUSSIONS

Results from the literature and model show that the integrated virtual model template may use gradation, crushing value, flakiness index, and absorption factor to identify the properties of the aggregates amongst a variety of others. Also, it ought to use the maximum density of the asphalt mix, bulk density of the specimen, bitumen content, void content, voids filled with bitumen, and then the marshal flow and stability as the critical parameters predicted. Subsequently, the template should also use the weight and properties of bitumen and filler content, additive, stone dust, and crushed stone as the input data values to predict the optimum bitumen content that completes the job mix formula. Further, the template's limit ranged from 1 to over a thousand data. Additionally, after rearranging the data, it produced the same outcome. As a result of management model development, the primary model, parameter sheet, and then the interface areas of the sheet all resulted.

The study inserted extra rows and columns before the "MIX" row. The CF row received the coefficient data obtained after simulating the sample data in the spreadsheet using the regression tool. The verification used random data from 62 past mix design observations extracted according to the Nigerian Specifications and inserted them into the "MIX" row. The values got interchanged for each row and column within the range of Numbers from one to infinity without exporting or importing new data from each row or column. However, they produced the exact summation and similar predictions.

Table 5. The coefficients from the virtual model

XPRED	Coefficients
X1	0.033763476
X2	0
X3	0.063468352
X4	-0.066605045
X5	0.075314781
X6	-0.053610259
X7	-0.030218209
X8	0.098467222
X9	-0.096915355
X10	-0.037234109
X11	-0.004307198
X12	0.158575485
X13	-0.09370069

Table 6. The observed bitumen versus the predicted bitumen content from test data

Y Observed	Y Predicted	Permissible Error	Actual Error
4.7	5.076370889	± 0.3	+ 0.37
5.3	5.57311017	± 0.3	+ 0.27
6.2	6.178556263	± 0.3	- 0.13
5.6	5.708637038	± 0.3	+ 0.10
5.3	5.57311017	± 0.3	+ 0.27
5.9	5.788181791	± 0.3	- 0.12
5.9	5.78178394	± 0.3	- 0.12
6.0	5.522586804	± 0.3	- 0.48
5.9	5.576463037	± 0.3	- 0.33
5.6	5.691800917	± 0.3	+ 0.09
5.5	5.351565246	± 0.3	+ 0.15
5.3	5.406469865	± 0.3	+ 0.10
5.5	5.45958849	± 0.3	+ 0.05
5.5	5.45958849	± 0.3	+ 0.05

The data for X14, X15, X16, and X17 represent the Filler (%), Aggregate Crushing Value (%), Aggregate Flakiness Index (%), Aggregate Absorption factor (%) and they were not available. So, the study used the available data. Table 5 below shows the coefficients against their "XPRED," representing the X data set used to predict. The summary output of the Regression Statistics indicates that the Multiple Regression returned 0.999372513, the Regression Square returned 0.998745419, the Adjusted Regression Square returned 0.958469411 while the Standard Error returned 0.221430503 for the 62 Observations. Table 6 below shows the observed bitumen versus the predicted bitumen content from test data.

The discussion resulting from verifying and developing the primary model, parameter, concept, and interface areas of the integrated virtual model sheet to manage the collated past asphalt mix design data for virtual simulation shows that the data after simulation returned several coefficients that predicted bitumen contents in Table 6 above. It shows that out of 14 random samples extracted, only 3 sample prediction values returned values outside the permissible error range. The model uses available data to predict desired results, and the observed errors are related to the reduced number of data according to literature and experience.

8. CONCLUSION

The paper got to meaningful conclusions and attained the study's aims. It paved the way for enhanced asphalt mix design simulation because it derived, formulated, and designed a meticulously crafted framework model template to manage, harness, input vital parameters and utilize real-world asphalt mix design past data that allows for better integrated spreadsheet-based virtual model simulation, a stride forward in asphalt engineering. The innovative framework includes areas with an information sheet, parameters, data input (aggregate data), and interface sheet (coefficient) orchestrated to seamlessly manage past asphalt mix design data.

The model allowed for the input and interplay of X and Y components, where the gradation (sieve size sizes), crushing value, flakiness index, and absorption factor represent the input independent variables of X. In contrast, the bitumen content represents the dependent variable of Y, a cornerstone of our virtual modeling architecture.

The study verified the model using several past data from the Nigerian locality. After summation, the template produced similar results, demonstrating remarkable consistency in its predictions, reinforcing the efficacy of the developed template as a reservoir of knowledge, and paving a pathway for utilizing available and reliable asphalt data for virtual simulations.

Therefore, we recommend that future researchers, especially those using similar localities and landscapes, expand their horizon of output variables to include other critical parameters such as the asphalt mixture maximum density, bulk density of the specimen, bitumen content, void content, voids filled with bitumen, and then the marshal flow and stability because it by doing so, we can elevate the predictive potential of future models and usher in a new era of asphalt mix design innovation.

Finally, this paper gives asphalt mix designers and modelers better insight into better data management in their specific localities and the ability to strive for excellence, leveraging data-driven insights to shape the future of asphalt engineering.

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