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# Traffic Road Emission Estimation Through Visual Programming Algorithms and Building Information Models: A Case Study

JORGE COLLAO<sup>1</sup>, HAIYING MA<sup>2,3</sup>, JOSE ANTONIO LOZANO-GALANT<sup>4</sup>, AND JOSE TURMO<sup>1</sup>

<sup>1</sup>Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya BarcelonaTech, 08034 Barcelona, Spain

<sup>2</sup>Department of Bridge Engineering, Tongji University, Shanghai 200092, China

<sup>3</sup>Shanghai Qizhi Institute, Shanghai 200003, China

<sup>4</sup>Department of Civil Engineering, University of Castilla-La Mancha, 13003 Ciudad Real, Spain

Corresponding author: Haiying Ma (mahaiying@tongji.edu.cn)

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**ABSTRACT** Emissions from transportation have a severe impact on the current climate crisis. Therefore, the estimation of these pollutants requires precise measurements that integrate both traffic and vehicle fleet information within a specific country or area. However, the current estimation tools continue using vehicle fleet standards based on recommendations or local studies. A problem for the current estimation models arises due to the difficulty of centralizing the large number of vehicle statistics. This article has taken advantage of the capabilities of both visual programming tools and building information modeling (BIM) to centralize databases from different sources, generating a model that integrates current traffic data and vehicle fleet statistics. The proposed platform estimates emissions and the carbon footprint using TIER 1 emission factors recommended by the European Environmental Agency (EEA). This platform has been successfully applied to a case study to estimate the carbon footprint of the B-20 road in Barcelona, using current vehicle restriction scenarios. This case study presents a maximum difference of  $-2.72\%$  compared with the estimations made by another similar report. This proposed platform more completely automates the communication among the equations and databases required to estimate traffic road emissions.

**INDEX TERMS** Building information modeling (BIM), COPERT, emissions impact assessing, green house gases (GHG).

## I. INTRODUCTION

Greenhouse gases (GHGs) are the largest contributors to the current climate crisis [1]. Therefore, the quantification of these gases is essential to estimate this environmental problem. Unfortunately, estimating these emissions is not an easy task.

The National Emissions Inventories (NEIs) are the main emission estimation instrument in most countries. In the case of road traffic emissions, the NEIs deliver their total results at the country level, considering the GHG emissions from vehicle fuel. Unfortunately, this information is not organized

by roads, which would allow studying different emission reduction strategies.

The NEIs also determine whether different countries are achieving emission reduction commitments from international agreements [2]–[4]. To reach these emission targets, the following strategies have been established: (1) restrictions to the circulation of polluting vehicles [5], (2) incentives to replace the vehicle fleet with models with low-emission fuels [6], (3) tax incentives that promote the use of public transportation, and (4) increases in the legal requirements for the environmental certification of vehicles [7].

The road emission estimation of NEIs requires the following databases: (1) Vehicle fleet data, which determine the distribution of the vehicle fleet in operation. (2) The vehicle traffic data, which determine the number of vehicles

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that use the roads. The NEIs have used different methods to translate the previous databases into GHG values. Some of these methods include (1) the CORINE AIR method [8], where vehicle length unit pollutants are associated with emission factors, (2) the HERMES model [9], representing the emissions through spatial-temporal distribution, and (3) the COPERT III software [8], based on the Ntziachristos and Samaras model [10]. Unlike the CORINE AIR method, this model associates different pollutant emission factors according to their origin (such as exhaust pipes, engine start, or tire wear). In the EU's NEIs, the most common tool is the COPERT IV software [11], [12].

The COPERT IV software is a tool that has been developed in coordination with the European Environment Agency (EEA) [13]. This model associates an average speed with the emission factor of a pollutant or the GHGs with the distance traveled by a specific vehicle. For this tool, the EEA has identified 3 levels (or tiers) of complexity to estimate road traffic emissions. These levels depend on the type and amount of information available from the respective traffic and vehicular fleet [14]. The definition of these levels is as follows:

(1) TIER 1: This level uses the fuel associated with the type of vehicle as an activity indicator associated with a specific emission factor. This level classifies the vehicular fleet inventory using the Nomenclature for Reporting (NFR) codification with the following categories: Passenger Cars (PCs), Light Commercial Vehicles (LCVs), Heavy-Duty Vehicles (HDVs), and L-Categories. A key limitation of this approach, however, is the way it assumes an average speed and a standard vehicle fleet. Nevertheless, this method continues to be recommended by the EEA, mainly for countries where there is no standard classification of their vehicle fleet or emission factors per unit of length traveled [14]. The applications of this TIER are scarce. In fact, only one work using TIER 1 was found in the literature. This work was developed by Stojanovic and Velickovic [15], who estimated the GHG emissions from traffic in the city of Novi Sad (Serbia). The researchers determined that the impact of cargo transport on the estimation had been undervalued in previous studies. However, they emphasized that their results were based on standard vehicle fleet due to the lack of detail regarding the country's fleet.

(2) TIER 2: This level also uses fuel as the main activity meter and associates a specific emission factor with the vehicle fleet with the same NFR codes as TIER 1. However, the vehicle categories defined by the NFR codes are broader and require more details. At the same time, the emission factors of different fuels are associated with a single average value. Some scholars that used this level are Dong *et al.* [16], who developed an alternative method for measuring evaporative emissions in different vehicle fleet-ing scenarios using semiempirical relations. They compared their results with COPERT and other emission models in the cities of Chicago (USA) and Guangzhou (China). The authors emphasized the need to fine-tune the calculation

of evaporative emissions in domestic inventories due to the differences presented in their research. Franco *et al.* [17] evaluated the GHG emission performance of various types of diesel vehicles on roads in Europe and the USA by developing a semiempirical emission measurement methodology. The authors compared the results of both regions and conducted field tests to validate the circulation of vehicles. However, their analysis only considered a part of the vehicle fleet. Therefore, their results are partial.

(3) TIER 3: This is the level that requires the most information regarding the vehicle fuel properties, including considering that both hot and cold emissions have different concentration characteristics. Some studies using this level of emissions data include Kotrikla *et al.* [18], who investigated the spatial distribution of particulate matter emissions in the city of Mytilene, Greece using in situ measurements of pollutant concentration, and Alam *et al.* [19], who studied Ireland's road network and determined that the previous emissions inventories underestimated the influence of PCs on estimations. The use of the different Tier levels in emission estimation studies depending on the scenario shows that their application often covers large areas and generally considers just a fraction of the total fleet in the study zone.

The statistics of national network traffic and vehicle fleets are extensive and have a considerable volume of data, which makes it a challenge to centralize this information efficiently in an environment that facilitates the association between these national data and emission calculation formulas. Overabundance of data can be as challenging as the lack of data, and engineers have to find ways to use it wisely in a practical form to make decisions [20], [21]. In the case of architecture, engineering and construction (AEC) projects, building information modeling (BIM) has emerged as the most suitable information management and monitoring engine for this type of process [22], [23]. BIM creates a collaborative environment that allows for the generation of information models of AEC projects that span their entire life cycle [24]–[26].

The following section presents the literature review of those works that have used a BIM environment to generate different types of flows of information to estimate the emissions of different stages of AEC life cycle projects.

## II. LITERATURE REVIEW

BIM has been applied to estimate emissions from vehicle traffic by several authors in different types of projects. On the one hand, in the case of infrastructure project applications, the following scholars are highlighted:

(1) Krantz *et al.* [27] developed a calculation system of built-in emissions based on the use of emission factors per unit of material. The system integrates a BIM model with a simulation model of different assembly processes to determine the built-in energy associated with the construction phase. The system was applied and validated on a semi-prefabricated beam of a bridge project. Although the platform proposed by this study was applied to infrastructure projects, its functions only estimate the carbon footprint of the

construction phase and do not consider other stages of the life cycle [28].

(2) Marzouk *et al.* [29] developed an integrated platform between the COPERT software and BIM models to determine the carbon footprint of road infrastructure projects throughout their life cycle. This platform integrates variables such as the unit emission per unit of material, performance and energy expenditure of construction equipment, duty cycles, energy expenditure, and environmental impact indicators. The platform was applied with success to six road infrastructure projects in Egypt with a total investment of 310 million dollars. However, this study did not consider the use of the official statistics of both the volume and the distribution of the vehicle fleet as estimation data.

(3) Kaewunruen [30] developed a digital platform of 6D BIM modeling. Their models were related to sustainability studies. Their platform incorporates information from a 3D model with a time schedule, cost estimation and carbon footprint analysis throughout the life cycle of a bridge project. This platform was applied to a bridge located in Ezhou city (China). However, their platform used emission factors recommended by the UK government, which are estimated using the UK vehicle fleet not the fleet of China. This reduced the accuracy of its results.

(4) Kim and Kim [31] proposed an integrated optimal design method for acoustic barrier tunnels by reusing steel beams. In the proposed method, information on reusable steel beams is extracted from the construction information modeling data of a noise barrier tunnel, and the optimization problem is defined. In addition, designs and plans for the acquisition of components with the aim of minimizing CO<sub>2</sub> emissions and costs are obtained through a multi objective genetic algorithm. This integrated design was implemented in a tunnel project located in the city of Seoul (South Korea). This method is very comprehensive with the emissions related to the whole life cycle of tunnels. However, its main contribution is associated with the emission estimation of structural component fabrication and not with the operation of the structural components.

On the other hand, in the case of building project applications, the following authors are highlighted:

(5) Marzouk *et al.* [32] integrated a BIM information model with emission calculations from the Athena Impactor Estimator software. This integration allows estimating the emissions of different construction assemblies during their development by associating variables such as equipment performance, working hours and emission factors, among others. This methodology was applied to a 3-story building project in Saudi Arabia with an isolated footing foundation solution. However, this publication can only be applied to projects with accurate information related to the variables that estimate construction equipment emissions.

(6) Yang *et al.* [33] developed an integrated BIM system that associates information about quantities from a 3D model in Autodesk Revit with a service management model in the Builder Design software, which contributes some emission

factors, to determine emissions throughout the project life cycle. The system was applied to a residential project in China, determining that operation and material production were the phases that most contributed to the total carbon footprint. This study was applied throughout the project's life cycle to determine the emissions associated with each phase.

(7) Zhou and Rezazadeh Azar [34] generated a BIM model information management system to determine GHG emissions and their reduction potential. The system was applied to a school building project of 40,000 m<sup>2</sup> in China, concluding that the concrete's manufacturing, transport, and placement work generated most GHG emissions. As in the previous study, the platform proposed by this study was configured only for the construction stages of building projects, reducing the flexibility for application to road projects.

(8) Li *et al.* [35] developed a carbon footprint calculation model for the fabrication phase of prefabricated concrete buildings combining BIM models with the estimation methodology recommended by the Intergovernmental Panel on Climate Change (IPCC) and the technology of the China Life Cycle Database (CLCD). This model was applied to investigate the carbon footprint of many building projects in China during the fabrication of their concrete. Despite the advanced details presented by this platform, its emission estimation model was focused on the fabrication stage and cannot be applied to other life cycle phases.

(9) Kurian *et al.* [36] presented an integrated platform to develop life cycle assessments combining BIM models and the environmental product declarations of materials used in construction, including their transport and estimation of the operational energy of the equipment. This platform was applied to a contextual investigation of a residential complex located in South India to determine the carbon footprint of residential buildings. Although this study is very complete, considering all the material fabrication processes, its emissions factors were recommended by private companies and not by official institutions. Therefore, these assessments can be subjective.

Table 1 summarizes the previous studies. This table includes the project type, the project stage, the BIM tools used, and the associated emission estimate software.

The information in Table 1 shows that the use of BIM in emission estimation processes has focused primarily on building projects. Its limited use for road projects has mainly been in the carbon footprint of the construction phases rather than the operational carbon footprint. In fact, despite its advantages, scholars have not given the potential use of this tool adequate attention, especially in studying the impact of GHG reduction strategies on road operation.

Figure 1 compares the number of publications (vertical axis) that estimate the emissions of AEC projects. Two groups of studies were considered: those that used BIM tools and those that did not use them. The period assessed was from 2013 to 2020 (horizontal axis). Figure 1a shows those publications from the Web of Science database [37],

**TABLE 1.** Featured studies on the use of BIM in estimating the emissions of AEC projects.

Project type	Estimation method	BIM software used	Emission estimation software	Aim	Reference
Infrastructure Project	Emission factors	Autodesk Revit	COPERT 4	Calculation of the incorporated emissions from bridge projects	[27]
Road project	Life cycle analysis	Autodesk Revit	Athena impactor estimator/COPERT	Calculation of the carbon footprint of road construction projects	[29]
Bridge structural assembly	Life cycle analysis	Autodesk Revit	ISO 14040	Emissions estimation of structural pieces assembly	[30]
Tunnel project	Life cycle analysis	Autodesk Revit	Designer Builder	Design method of acoustic barrier tunnels by reusing steel beams	[31]
Building project	Emission factors	Autodesk Revit	Athena impactor estimator	Emissions estimation of the construction phase	[32]
Building project	Life cycle analysis	Autodesk Revit	Design Builder	Emission management system information model	[33]
School project	Life cycle analysis	Autodesk Revit/DYNAMO	RS Means Database	Calculation of the emissions from the assembly processes of structural systems	[34]
Building project	Life cycle analysis	Autodesk Revit	Autodesk insight	Calculation of the carbon footprint during the material fabrication stage	[35]
Housing complex projects	Life cycle analysis/Emission factors	Autodesk Revit	Green building studio	Estimation of the carbon footprint during the life cycle of materials manufacturing	[36]

and Figure 1b shows the studies found in the Scopus database [38].

An analysis of Figure 1 reveals that the use of BIM in the estimation of GHG and pollutant emissions remains scarce. This can be explained by recognizing that BIM is still being introduced into this industry. Additionally, the use of BIM in AEC projects has been concentrated in the modeling and management process rather than in the areas of simulation or impact analyses [39]–[41]. This reveals an opportunity to further develop the use of BIM in the area of GHG estimation, especially in automating emissions calculations and developing specific modules that study the impact of emission reduction strategies on a given road.

Literature analysis shows that emission estimates in large areas use information about the vehicle fleet and traffic statistics from the road network for the calculations. However, the results of these analyses are presented only as national totals and are not separated by specific roads. This limitation reduces their ability to help develop measures that would ensure local compliance with national GHG reduction commitments. On a local level, road traffic emission studies have mainly developed models that minimize uncertainty in calculations or improve estimation models. However, these analyses only consider a fraction of the vehicle fleet in the country, which limits the scope of their studies [42]. This limitation is caused, in part, by a lack of automation in processing the national traffic and vehicle fleet information in the estimation models. Automation reduces calculation time significantly and increases the practical applicability to GHG reduction studies.

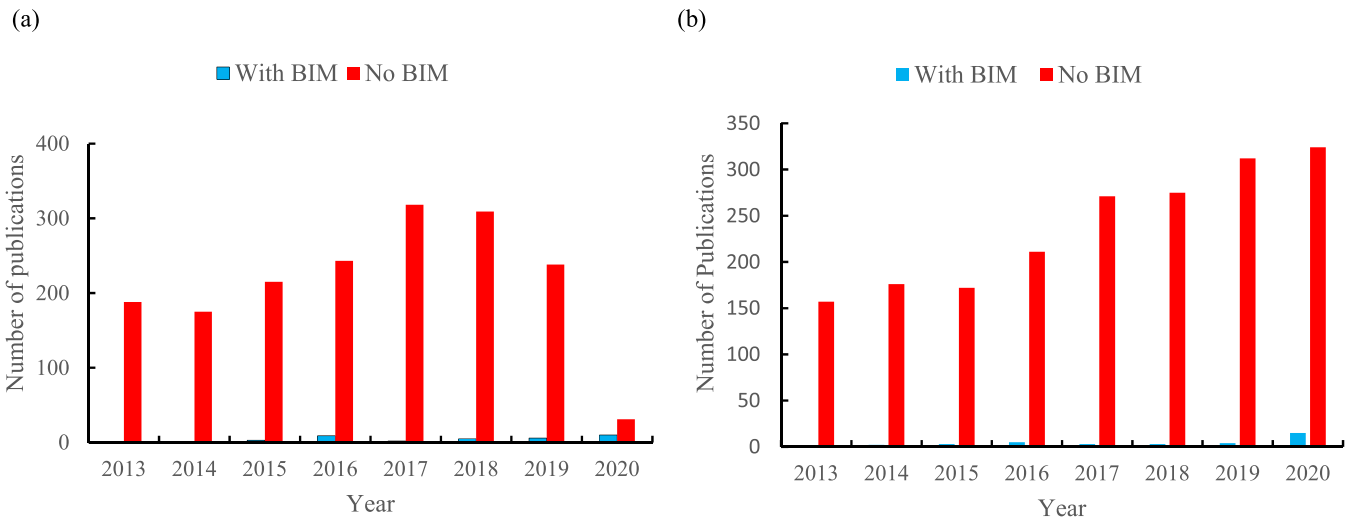
This paper proposes a calculation module to estimate the GHG emissions for vehicle traffic on specific roads in any

country that has the appropriate traffic and fleet data. The main novelty of this method is the automated integration of the GHG emission factors recommended by the EEA TIER 1 level with a virtual BIM model. The estimation method recommended by the NEI is used as a basis. In general, the proposed platform consists of connecting information on the road traffic and vehicle fleet in a specific country with a BIM model that has associated vehicle families with properties that can estimate GHG variables. This connection makes it possible to automate the process and calculate the GHG or operational carbon footprint of a specific road. Specific calculation modules have been developed using the same BIM model to measure the impact of emission reduction strategies.

This paper is organized as follows: Section 3 describes the tools, processes, and concepts developed for the proposed estimation platform. Section 4 presents a study case that validates the proposed platform. In this study case, two emission scenarios were studied: (1) the calculation of the carbon footprint of a road in the Province of Barcelona (Spain); and (2) an impact assessment of a current vehicle restriction program as a reduction strategy on the emissions of a road. Section 5 presents the results and offers further discussion of the study. Finally, the main conclusions, limitations, and future study proposals are presented in Section 6.

### III. METHODOLOGY

In this section, the concepts and tools necessary to develop the proposed emission calculation platform are presented. This platform requires the following two components. (1) Databases that collect road traffic information and vehicle fleet details in a specific country. These databases provide the necessary information to calculate emissions for



**FIGURE 1.** Comparison of research publication on emissions estimation: with BIM and without BIM – (a) the Web of Science and (b) the Scopus databases.

specific roads. (2) BIM model that centralizes the data from the databases in an environment that estimates emissions based on the EEA TIER 1 level. More specifically, the platform requires the following three fields: (1) georeferenced maps, which extract road traffic information using ESRI's ArcMap software [43], (2) BIM software (such as Autodesk Revit), which is used to generate an emission estimation model [44], and (3) a BIM Plugin, such as the DYNAMO visual programming software, which allows connecting the databases with the BIM model [45].

The flow chart to develop this proposed platform is divided into three levels. The first level contains the traffic, road, and vehicle fleet databases. The road traffic and vehicle fleet information was prepared by extracting information from the georeferenced maps in countries that have this information and from statistical reports of their vehicle fleet distributions. The databases are organized as a spreadsheet (.xls) using MS Excel software. The second level contains the DYNAMO nodes, which link the traffic and vehicle fleet databases with the BIM model. The format of the nodes is DYN. The third level contains the emissions calculation BIM model. This model is composed of the vehicle families with TIER 1 emission properties. The emission calculations and impact of reduction strategies were developed in quantity tables using the Revit software. The BIM families and model are saved in .rfa and .rvt formats, respectively.

The following subsections describe the specific processes and concepts necessary to develop each of these three levels.

#### A. ROAD TRAFFIC AND VEHICLE FLEET DATABASE

In this section, the instruments and concepts necessary to build the road traffic and vehicle fleet databases of the proposed platform are described. The different types of vehicles in the databases use their associated fuel type as the main filter since the TIER 1 level data only support a limited number of fuels.

Several government entities in charge of the administration and management of national road networks have generated digital tools or public documentation about traffic data and vehicle fleet characteristics of their respective networks. One of these entities is the US Federal Highway Administration, which presents detailed information on traffic using different types of roads. These data are available at four distinct levels: rural, urban, interurban, and interstate routes [46]. Examples of European government entities include the General Roads Directorate in Spain [47]; the Department for Transport in Great Britain [48]; and the General Directorate for Infrastructure, Transport, and the Sea in France [49]. Similar to the US Federal Highway Administration, these agencies also provide statistics and georeferenced maps of specific road sections within their network and detailed vehicle fleet categories.

The main measure of vehicle volume supported by road networks is called travel [50]–[52], which is a product of the number of vehicles that have circulated on a given road and its length [47]. This parameter represents the number of vehicles multiplied by the unit length of the road, [veh-km] or [veh-miles] [53]. This variable quantifies the actual number of vehicles that generate the operational carbon footprint of a specific road.

Four columns of data are required to build the road traffic database, including (1) the name and type of road, (2) the associated administrative unit (province, district, or municipality), (3) the road length, and (4) the travel value.

The methodology recommended by the United Nations Framework Convention on Climate Change (UNFCCC) was used to build the vehicle fleet database [54]. This methodology extracts statistical reports and the number of registered vehicles (by category) from the transport or traffic directories of each country [55]–[57]. The different vehicle categories are distributed as a percent of the total fleet of vehicles associated with a given administrative unit. Finally, this distribution is applied to the travel value of the road. This procedure



**TABLE 2.** Road traffic database.

Road name	Length [km]	Province	Total travel value [veh-km]	Travel value heavy vehicles [veh-km]	Travel value light vehicles [veh-km]
A-23	7.27	Zaragoza	27,246,648	7,666,105	19,580,543
A-23	5.65	Zaragoza	22,864,165	6,628,071	16,236,094
A-23	16.85	Zaragoza	69,756,133	20,012,913	49,743,220
A-23	7.77	Zaragoza	24,846,633	6,571,127	18,275,506
A-23	5.46	Zaragoza	24,799,645	5,185,525	19,614,120
A-23	9.67	Zaragoza	43,921,718	9,183,889	34,737,829
A-23	7.49	Zaragoza	40,655,081	7,168,154	33,486,927
A-23	7.13	Zaragoza	50,875,293	7,466,429	43,408,864
AP-2	24.58	Zaragoza	145,756,616	31,494,005	114,262,611
AP-2	23.91	Zaragoza	137,201,837	25,826,884	111,374,953
AP-2	3.73	Zaragoza	19,354,727	3,960,961	15,393,766
AP-68	12.30	Zaragoza	48,725,732	4,580,960	44,144,772
AP-68	23.17	Zaragoza	123,745,798	11,166,454	112,579,344
AP-68	1.83	Zaragoza	8,958,048	795,106	8,162,942
AP-68	17.50	Zaragoza	104,973,870	8,114,503	96,859,367

characterizes the traffic volume of a road according to the vehicle categories of the associated country [14].

The criteria recommended by the 2020 NEI of Spain [58] are used to link the travel and vehicle fleet distribution values from the previous databases with the TIER 1 emission factors, which provide factors for four types of fuels: petrol, diesel, liquefied petroleum gas (LPG), and compressed natural gas (CNG) [14]. However, these fuels represent only a portion of the total vehicle fleet. In addition, this portion also contributes partially to the total travel value of the road. To make this adjustment, an auxiliary variable called the Vehicle Fleet Correction Factor (VFCF) is incorporated into the proposed platform. This variable describes the relation between the number of vehicles (ENV) with TIER 1 fuel types and the total number of vehicles (TNV) in a specific territorial unit (department or province). The ENV and TNV values are presented in units of vehicles, [Veh]. The calculation of this auxiliary variable is presented in Equation (1).

$$VFCF = ENV / TNV \quad (1)$$

Finally, to obtain the value of the effective travel of the road (ETR) for which the emissions are determined, the VFCF value (1) is applied to the travel value in the traffic database. The calculation of the ETR value is presented in Equation (2) [14].

$$ETR = ITR * VFCF \quad (2)$$

where ETR is an annual number of km traveled by a vehicle fleet using TIER 1 fuel types, ITR (initial travel road) is the real number of km traveled on the road during operation, and VFCF is the vehicle fleet correction factor associated with

the road. The units of ETR and ITR are quantified in number of vehicles per unit of length, [veh-km] or [veh-miles].

The databases proposed in this study are summarized in the matrices presented in Table 2 and Table 3. On the one hand, Table 2 shows the road traffic database extracted from the official information of the General Roads Directorate of Spain [43]. This table includes the following columns: (1) the road name, (2) the associated province, (3) the total travel value, (4) the total travel value of heavy vehicles, and (5) the total travel value of light vehicles. On the other hand, Table 3 presents the distribution of the national vehicle fleet from official statistics of the Directorate-General for Traffic of Spain [44]. The information in this table is organized in the following columns: (1) the territorial units associated with the roads and (2) the percentage of distribution of the different types of vehicles recognized by the government of Spain. However, the columns vary according to the vehicle type and method of presentation of road traffic for each country.

## B. GENERATION OF THE IMPORT/EXPORT NODES IN DYNAMO

The connection between the information from the traffic and vehicle fleet databases in Section 3A and the BIM information model was generated through visual programming nodes carried out in DYNAMO. These nodes refer to specific operations that logically organize the input and output information from a specific algorithm [45]. This proposed platform used the following types of nodes: (1) Data.Export. Excel, which transfers the parameters of the name and province of the road from the BIM model to the databases of the proposed platform. Then, the road traffic database provides an effective

**TABLE 3. Vehicle fleet distribution database.**

Autonomous community	Province	% Cargo Truck up to 3,5 T-Diesel	% Cargo Truck Over 3,5 T - Diesel	% Van-Diesel	% Industrial Tractor-Diesel	% Bus - Diesel	% Bus - CNG	% Cars - Diesel	% Cars - LPG
Andalucía	Almeria	13.97%	48.13%	10.44%	47.33%	4.54%	0.00%	75.47%	0.12%
Andalucía	Cádiz	10.93%	57.27%	7.50%	32.32%	10.32%	0.09%	81.46%	0.11%
Andalucía	Cordova	10.24%	60.88%	13.47%	32.62%	6.10%	0.41%	76.17%	0.12%
Andalucía	Granada	11.75%	55.35%	12.81%	35.14%	9.51%	0.00%	75.33%	0.12%
Andalucía	Huelva	12.97%	51.57%	8.17%	38.55%	9.88%	0.00%	78.77%	0.09%
Andalucía	Jaen	12.59%	56.96%	18.96%	36.92%	6.13%	0.00%	68.35%	0.10%
Andalucía	Malaga	11.53%	59.71%	12.11%	30.31%	9.95%	0.03%	76.11%	0.25%
Andalucía	Sevilla	10.79%	52.37%	6.89%	39.10%	7.22%	1.32%	82.15%	0.17%
Aragón	Huesca	16.07%	50.44%	14.28%	42.44%	7.12%	0.00%	69.54%	0.10%
Aragón	Teruel	14.93%	46.18%	15.28%	51.40%	2.41%	0.00%	69.73%	0.06%
Aragón	Zaragoza	10.88%	47.27%	11.77%	44.81%	7.92%	0.00%	77.02%	0.33%
Asturias	Asturias	8.17%	57.31%	10.39%	31.97%	10.61%	0.11%	81.26%	0.18%
Baleares	Islas Baleares	19.35%	63.32%	11.60%	16.85%	19.21%	0.62%	68.85%	0.19%
Canarias	Palmas	34.54%	62.84%	19.82%	17.09%	20.07%	0.00%	45.16%	0.48%
Canarias	Santa Cruz	35.53%	62.67%	21.72%	15.95%	21.38%	0.00%	42.49%	0.26%

travel value and road length. The vehicle fleet database provides a percent distribution of the different vehicles. (2) Data.Import.Excel, which allows the previous values of the databases to be transferred to the BIM model to estimate the emissions for a given road.

Figure 2 presents the flow chart of the export and import nodes for the proposed platform. In this figure, the ellipses represent the type of nodes used, the rectangles indicate the instrument associated with each node (database or BIM model), and the text identifies the variables that are exchanged between these instruments. Finally, the arrows show how each node carries these parameters to the various instruments.

Figure 3 shows the structure of the nodes used in this study. These nodes extract the name and associated province from the BIM model. This information is connected to the databases of the proposed platform through the file path. Figure 3a shows the structure of the import nodes, where the BIM model extracts values from the traffic (Figure 3b) and vehicle fleet (Figure 3c) databases. Then, these values are associated with global parameters of the same name in the BIM model.

### C. EMISSIONS CALCULATION USING THE BIM MODEL

To calculate GHG and pollutant emissions, the BIM model includes two main components. The first component is the BIM vehicle families, which categorize vehicles from a specific country and import them into the BIM model in the form of parametric families [60] with specific information on fuel type and emission factors [61], [62], as well as other properties. The second component is the tables of quantities. The BIM model determines the emissions or carbon footprint of each vehicle family based on the information extracted from the DYNAMO nodes and the emission properties of each

family. Following UNFCC recommendations, this proposed platform separates emission estimates into two groups [14]: (1) pollutants, such as CO, NH<sub>3</sub>, or SO<sub>2</sub>, and (2) GHGs, such as CO<sub>2</sub> and NO<sub>2</sub> [14].

To determine the carbon footprint, this platform applies the recommendations of the US Environmental Protection Agency [63] and the Intergovernmental Panel on Climate Change (IPCC) [64], both of which describe the necessity to take into account the heat capture effect of GHGs. Therefore, this platform uses the Global Warming Potential Index (GWP Index) in the calculation of CO<sub>2</sub> and NO<sub>2</sub> emissions with values of 1 and 265, respectively, and a horizon of 100 years [64].

The TIER 1 emission factors associate each pollutant or GHG with three intensity levels: minimum, average and maximum [14]. The levels are assigned based on some Boolean rules [65]. These restrictions were associated with an auxiliary variable called the traffic factor (TF), which depends on the road function for its assignment. The TF can only have three values: minimum  $-1$ , average 0 and maximum 1. This assignment considers the following qualitative categories: (1) Urban roads (TF =  $-1$ ), which are roads with a high traffic load. Therefore, both the vehicle speed movement and the emission factor per vehicle are minimal. (2) Alternative roads (TF = 0), which describe some areas with specific infrastructure (ports, airports, or escape zones). The movement speed is higher than urban roads. Therefore, the emission per vehicle is considered average. (3) Expressways (TF = 1), which are high-speed roads. Therefore, the emission factor per vehicle unit is maximized.

TIER 1 Emission factors are organized as units of emission per kilogram of fuel consumed [14]. For this work, each vehicle family from the BIM model is associated with a Unitary Fuel Consumption variable that depends on the

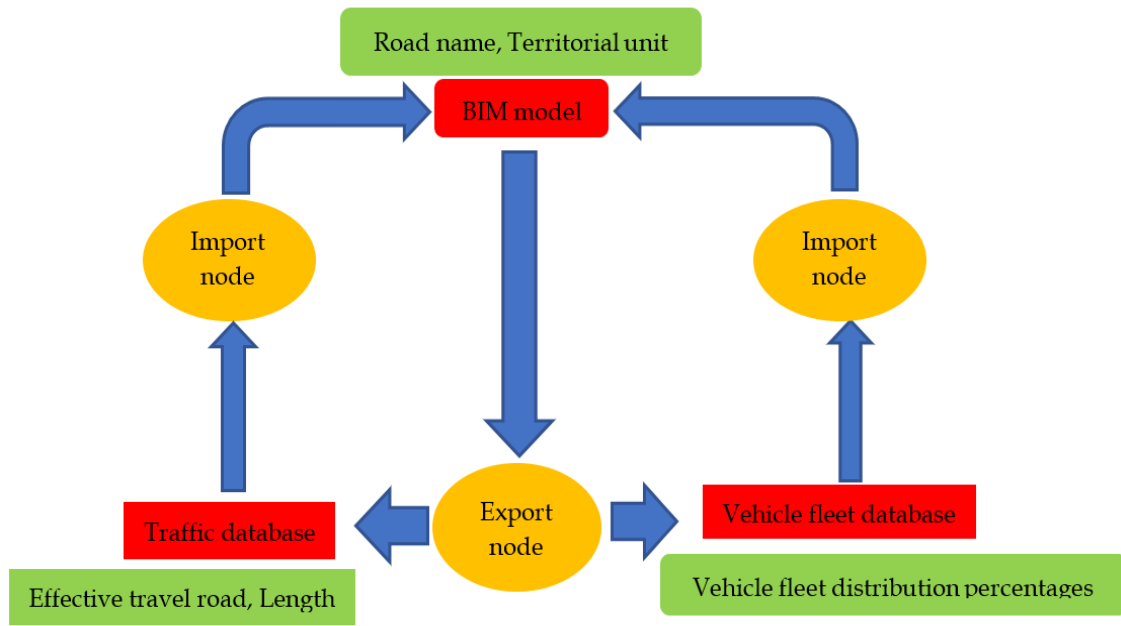


FIGURE 2. Proposed DYNAMO nodes flow.

TABLE 4. TIER 1 fuel consumption factors [14].

NFR Category	Vehicle	Fuel (Type)	Typical Consumption ( $\text{g}\cdot\text{km}^{-1}$ )	Fuel
PC		Diesel	60	
		LPG	57.5	
LCV		Diesel	80	
		Diesel	240	
HDV		CNG	500	

fuel associated with the type of vehicle. Table 4 lists the fuel consumption values recommended by the EEA for the passenger cars (PCs), light commercial vehicles (LCVs), and heavy-duty vehicles (HDVs).

The product between the typical fuel consumption values in Table 4 and the length of the road (imported from traffic database) determines the fuel consumed by a specific type of vehicle family. As a result, the fuel consumption (FC) for a vehicle family is calculated as follows [14]:

$$FC = \frac{RL * UCF}{1000} \quad (3)$$

where road length (RL) refers to the total length of the road under study and unitary fuel consumption (UCF) refers to the fuel expense per road kilometer traveled. The UCF is measured in units per kilogram, and the RL is measured in kilometers.

The tables developed to estimate annual emissions require the following input parameters: (1) the vehicle family,

(2) the fuel type, (3) the fuel consumed, (4) the pollutant or GHG emission factor, and (5) the effective number of vehicles from each of the families (derived from the BIM model).

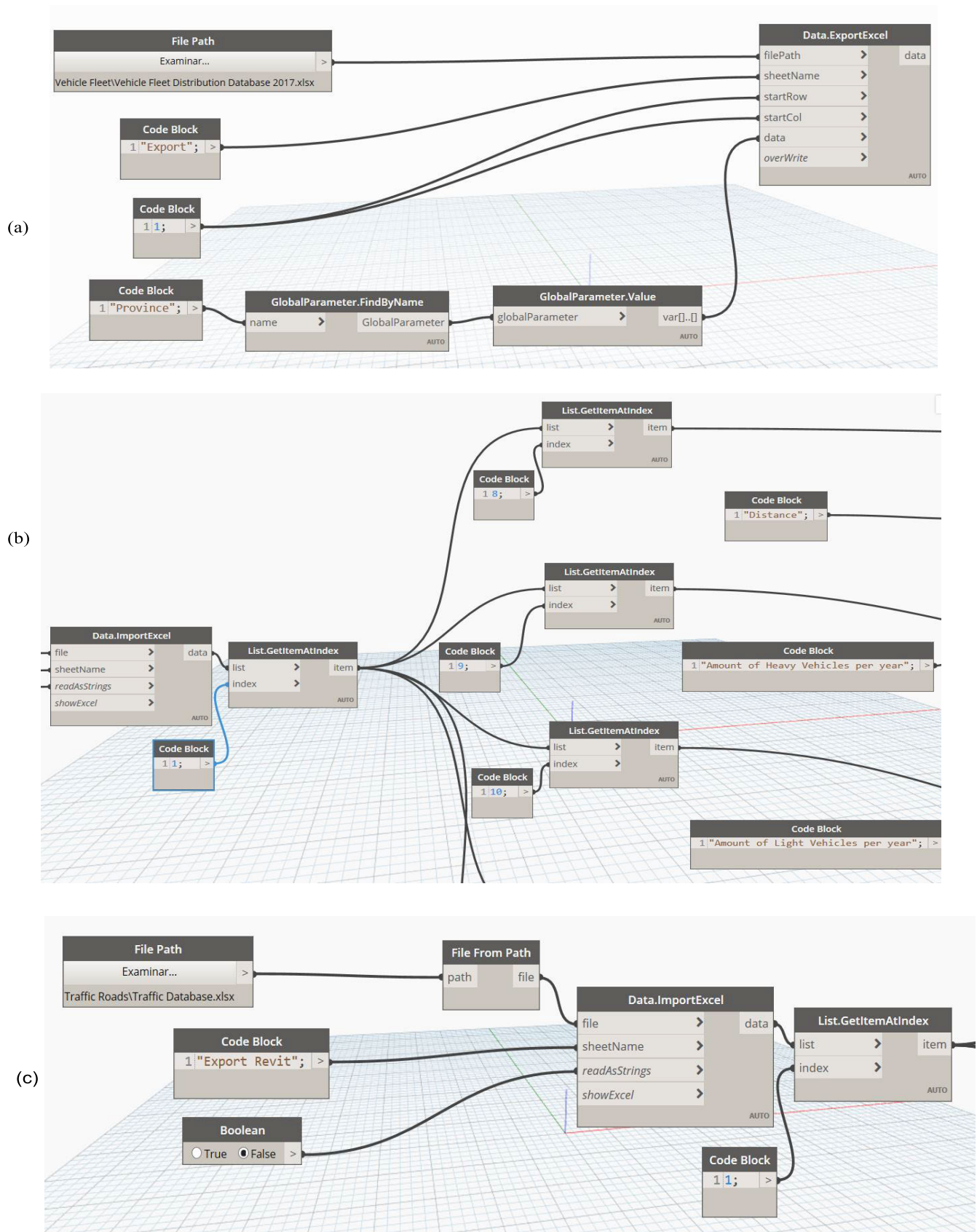
The annual emissions of each pollutant or GHG are determined by creating a calculated field in the table and relating the input variables with the emissions by weight (kg). The total emissions (TE) of pollutants (or GHGs) generated by a specific type of vehicle are calculated as follows [14]:

$$TE = \frac{FC * AFV * EF}{1000} \quad (4)$$

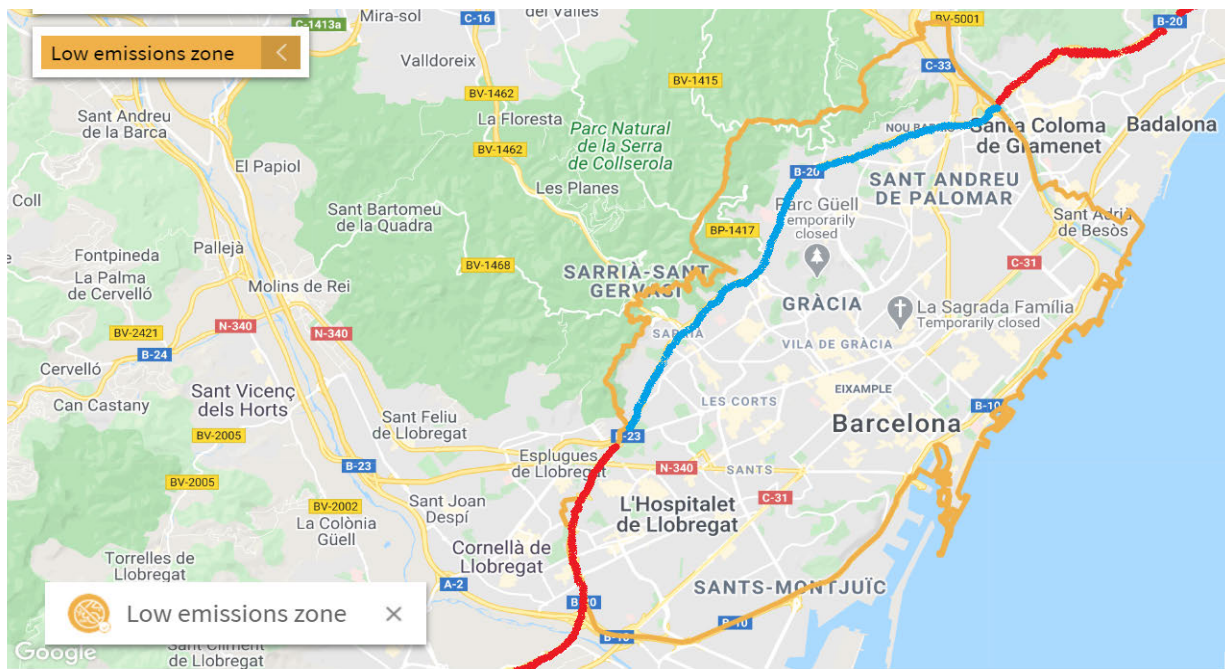
where the fuel consumed (FC) refers to the fuel consumed per vehicle unit, the amount of family vehicles (AFV) refers to the number of vehicles categorized as a specific type that used the road under study, and the emission factor (EF) refers to the amount of the pollutant or GHG emitted per unit of fuel consumed.

The current vehicle fleet market tends to use low-emission fuels due to mandatory emission reduction standards [66], [67]. Therefore, research on the road carbon footprint should also integrate these propellants [68], [69]. The platform proposed in this study has excluded these fuels because it uses TIER 1 factors. However, the BIM model generated from this platform can also integrate these excluded fuels. This integration uses the following procedure: (1) Add vehicle families, different types of vehicles can be generated by duplicating and renaming families already present in the BIM model. (2) Create emission parameters, the vehicles created by step (1) are associated with emission factors created from the BIM model as custom parameters [62]. (3) Connect with Dynamo, the emission factors of step (2) are associated





**FIGURE 3.** (a) Export node structure, (b) Import node structure for traffic data, and (c) Import node structure for vehicle fleet data.



**FIGURE 4.** Section of the B-20 road in the LEZ is represented using Google Maps format [71]. Red lines mark the sections of the road not affected by the LEZ, while the blue lines highlight the section impacted by the LEZ program.

with the databases developed by this study through Dynamo scripts.

In the next section, the proposed methodology is applied to a case study to illustrate its applicability in the estimation of GHG emissions and the carbon footprint generated during the use of a specific road. The impact of different strategies on reducing emissions is also studied.

#### IV. CASE STUDY

In this case study, the proposed platform is used to determine the carbon footprint ( $\text{CO}_2$ ) and  $\text{NO}_x$  emissions of different operating scenarios for the B-20 road in the Province of Barcelona (Spain). The results can be used to assess the impact of Barcelona's Low Emissions Zone (LEZ) vehicle restriction program. The LEZ program aims to create a  $95 \text{ km}^2$  area around the city of Barcelona that restricts the circulation of the most polluting types of vehicles [70]. This strategy aims to reduce the population's exposure to high emissions of pollutants and improve the environment. This case study only determines vehicle exhaust emissions. Information is extracted from the Spanish road network (SRN) to build the traffic database, while the vehicle fleet information comes from the Spanish Directorate-General of Traffic (DGT).

The results of this case study are validated by comparing them with one report presented by the Urban Development Agency of Barcelona [71]. This report estimated the impact of the LEZ program on emissions in various sectors and main roads of the city using a TIER 3 COPERT level and EEA recommendations [14]. This report is considered a validation study and considers the following scenarios. (1) The base

scenario corresponds to the emissions of the opening year of the LEZ program (2017). These data serve as a reference to measure and evaluate the effect that the LEZ program has had on other scenarios. (2) The 2020 Tendencia-LEZ represents the emissions generated once the LEZ program was in effect in 2020. In both scenarios, only the  $\text{NO}_x$  emissions of the B-20 road are specifically estimated. The same scenarios were studied in this case study but using real statistics of the vehicle fleet in 2017 and 2020.

In Section 4A, the quantitative data of the road under study are described in terms of length and traffic situation, followed by an explanation of the different estimation scenarios. Then, the 2017 and 2020 emissions scenarios are presented in Section 4B and Section 4C, respectively.

##### A. DESCRIPTION

The B-20 road has a length of 26 km. A total of 13.1 kms are managed by the SRN [49], and Barcelona Town Hall is responsible for the remaining 12.9 km [72]. This road represents 4.25% of the total length of roads in Barcelona Province. A total of 4.17% and 10.9% of the total travel on the B-20 comes from heavy and light vehicles in the province, respectively. The B-20 road is classified as an urban road according to the Metropolitan Area of Barcelona [73] and is assigned a traffic factor of  $-1$ . Figure 4 shows the section of the B-20 in Barcelona's LEZ project perimeter, which is organized by colors as follows: (1) red lines highlight sections of the B-20 road administered by the SRN and remain outside the LEZ; (2) blue lines identify sections of the road managed by the Barcelona Town Hall and are within the LEZ; and



**TABLE 5.** SRN roads traffic database [67].

Road name	Length [km]	Province name	Total travel value [veh-km]	Travel heavy vehicles [veh-km]	Travel light vehicles [veh-km]
B-20	2.29	Barcelona	131,067,130	7,246,819	123,820,311
B-20	0.7	Barcelona	40,064,188	2,215,185	37,849,003
B-20	7.97	Barcelona	305,403,703	26,321,084	279,082,619
B-20	2.14	Barcelona	82,003,000	7,067,392	74,935,608
Total	13.1	-	558,538,021	42,850,480	515,687,541

**FIGURE 5.** SRN 2017 traffic map web viewer [59].

(3) gold lines mark the perimeter of the LEZ. For this study, the red sections are called the exterior length, and the blue section is called the interior length.

### B. BASE SCENARIO

The 2017 traffic map from the SRN is used to generate the traffic database [59]. The SRN recognizes two types of vehicles [71]: (1) heavy vehicles, defined as a load greater than 3.5 t and a weight greater than 6 t, and (2) light vehicles, which have a cargo and weight lower than the heavy vehicle values. The traffic map provided by the SRN is web-based and presents road data in the form of spreadsheets and includes the following information: (1) road kind, (2) road length, and (3) travel value of heavy and light vehicles, and (4) average daily vehicle intensity [59]. This instrument collects information on 52.3% of national traffic and 65.3% of the heavy traffic [71]. Table 5 lists the traffic information of the B-20 road in spreadsheet format, while Fig. 5 provides an example of the same road data but presented in the web-based interface.

According to Table 5, the exterior length of the B-20 road has an annual travel value of 42,850,480 [veh-km] for heavy vehicles and 515,687,541 [veh-km] for light vehicles. According to the Barcelona Town Hall [71]–[74], the interior length has an annual travel value of 741,103,775 [veh-km]. However, this value does not distinguish heavy vehicles from light vehicles. In this study, urban road vehicle fleet distribution percentages measured by the Metropolitan Area of Barcelona are used to estimate these values [73]. For the B-20 road, these percentages are 7.1% heavy vehicles and 92.9% light vehicles. These percentages translate into travel values for heavy and light vehicles on the inner length of 52,618,368 [veh-km] and 688,485,407 [veh-km], respectively.

The vehicle fleet distribution database is generated using information from the Directorate-General for Traffic (DGT) statistical portal, which describes the vehicle fleet by province [56]. The filters used include (1) the vehicle type, (2) the fuel type (diesel, LPG and CNG), and (3) the associated province.

**TABLE 6.** Association of the SRN, DGT, and EEA vehicle categories.

SRN category	DGT category	Fuel	EEA category
Heavy vehicles	Cargo truck on 3,5 t	Diesel	Heavy duty vehicles
	Industrial tractor	Diesel	
	Bus	Diesel CNG	
Light vehicles	Vans	Diesel	Light vehicles
	Cargo truck up 3,5 t	Diesel	
Light vehicles	Turismo	Diesel LPG	Passenger cars

**TABLE 7.** Distribution of the vehicle fleet for the 2020 emissions scenario - Barcelona province.

SRN category	DGT category	PDOVF [%]
Light vehicles	Cargo Truck up to 3,5 t - Diesel	12.12%
	Van-Diesel	12.29%
	Cars-Diesel	75.35%
	Cars-LPG	0.23%
Heavy vehicles	Cargo Truck on 3,5 t - Diesel	61.00%
	Industrial Tractor - Diesel	27.97%
	Bus - Diesel	10.38%
	Bus - CNG	0.66%

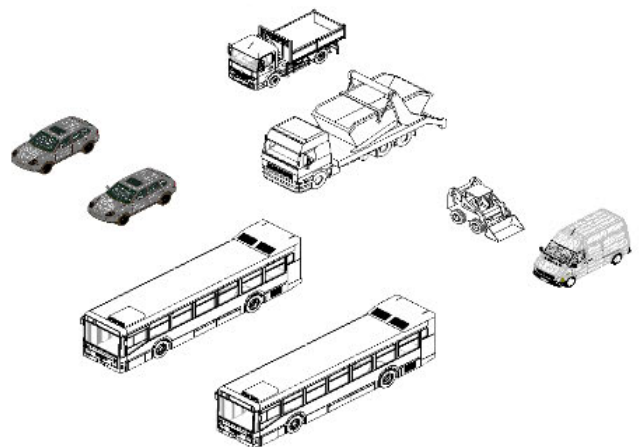
The DGT, SRN and EEA each establish their own vehicle categories. To compare these categories, this study considers the similarities between the different vehicle classifications in terms of weight, load, and functionality [75]. However, not all DGT vehicle categories specify the fuel type, which is the case for trailers and semitrailer trucks. For this reason, these vehicles are excluded from the vehicle fleet considered in this study. Another important exclusion is the L-category vehicles that only specify gasoline as the associated fuel type, which is not a recognized TIER 1 category [14]. Table 6 presents the classification of vehicle categories according to the SRN, DGT and EEA criteria applied in this study.

Together, the information in Table 6 combined with the DGT vehicle fleet data can be used to standardize the vehicle category distribution percentages at the province level. These percentages are applied to the travel value in the corresponding groups of heavy and light vehicles. In this way, the number of vehicles belonging to a specific category that use the B-20 is determined. Table 7 shows the percentage distribution

of the vehicle fleet (PDVF) in Barcelona Province considered in this scenario.

The vehicle fleet in the province of Barcelona is made up of 51.0% heavy vehicles and 42.3% light vehicles. This corresponds with the TIER 1 fuel types [56] and can be represented as VFCF values of 0.510 and 0.423, respectively.

Figure 6 presents the 3D BIM model developed in Autodesk Revit for this study. Each generic family corresponds to a specific vehicle category listed in Table 6. Table 8 shows the calculation format used to estimate the CO<sub>2</sub> emissions.

**FIGURE 6.** 3D BIM model of the study.

### C. 2020 TENDENTIAL-LEZ

Although the LEZ program permanently restricts the circulation of high emission vehicles. This restriction does not apply to certain roads that are internal to the LEZ due to their designation as urban arteries. This is the case of the B-20 road. To evaluate this scenario, this study considered the following two estimate values used by the validation study [7]. (1) Percentage of heavy vehicles, which reaches 5.6% for the exterior and interior length, (2) travel value, which presents a reduction average of 2.76% from their 2017 values. In other words, for this scenario, the exterior length of the B-20 road has travel values of 30,414,853 [veh-km] for heavy vehicles and 512,707,519 [veh-km] for light vehicles. In the interior section, these values are 40,356,361 [veh-km] and 680,292,949 [veh-km] for heavy and light vehicles, respectively.

The travel values corrected for the 2020 emissions scenario are used as global parameters in the BIM model in this study. Then, these values are linked to the parameter number of heavy vehicles per year in the same model. No adjustments should be made to the vehicle fleet database because the LEZ program restriction does not affect this particular road [76].

To build the vehicle fleet database for this scenario, the DGT statistics for 2020 are used with the same filters as in the 2017 emissions scenario, Table 9 presents Barcelona's vehicle fleet distribution percentages for 2020. This table

**TABLE 8.** CO<sub>2</sub> emissions calculation table format.

Vehicle family	Fuel [Type]	Fuel Consumed [kg]	CO <sub>2</sub> Emission Factor [g/kg]	Amount of Family Vehicles [Veh]	CO <sub>2</sub> Emissions [kg]
Cargo Truck Over 3,5 T - Diesel	Diesel	3.096	3.169	1,288,557	12,642,316.552
Cargo Truck up to 3,5 T - Diesel	Diesel	1.032	3.169	2,728,674	8,923,877.546
Industrial Tractor - Diesel	Diesel	1.032	3.169	581,676	1,902,317.173
Van - Diesel	Diesel	1.032	3.169	2,789,473	9,122,715.750
Cars - Diesel	Diesel	0.774	3.169	17,714,395	43,449,974.988
Cars - LPG	LPG	0.742	3.024	17,421	39,075.967
Autobus - Diesel	Diesel	3.096	3.169	219,340	2,151,991.766
Autobus - CNG	CNG	6.450	2.743	666	11,779.334
Total CO <sub>2</sub> emissions					78,244,049.076

includes the percentage variation of each vehicle category when compared to the base scenario.

## V. RESULTS AND DISCUSSION

In this section, the results of the GHG emission estimates of the scenarios proposed in Section 3 are presented. Table 10 shows the carbon footprint generated by vehicular traffic on the B-20 road in both scenarios. The results differentiate the CO<sub>2</sub> and NO<sub>2</sub> emissions for each vehicle category listed in Table 6.

Table 10 shows a reduction of 24.95 [kt CO<sub>2</sub> Equiv] in the 2020 emissions scenario compared with 2017. In other words, our platform has determined that the indirect implementation of the LEZ program in the B-20 road's operation reduces its carbon footprint by 17.03%. However, the validation study estimates an average LEZ interior reduction of just 4.03% [7].

In general, terms, both studies indicate lower emissions since the application of the LEZ program. Nevertheless, the platform developed in this study indicates a larger reduction for the two following reasons: (1) Analysis area, our platform only considered the information of the road, however, the validation study incorporated the influence of other nearby areas increasing the uncertainty of its estimations, (2) road traffic data, this study considered real operative data (2020) about road traffic, however, the road travel values from the validation study were estimated.

According to Table 10, the highest emission vehicle categories in the 2017 emissions scenario were cars with 82.24 [kt CO<sub>2</sub> Equiv] (56.13%), followed by cargo trucks with 39.7 [kt CO<sub>2</sub> Equiv] (27.09%), and vans with 17.24 [kt CO<sub>2</sub> Equiv] (12.6%). In the case of the 2020 emissions scenario, the highest emission categories were cars with 68.62 [kt CO<sub>2</sub> Equiv] (56.44%), followed by cargo trucks with 31.5 [kt CO<sub>2</sub> Equiv] (25.9%), and vans with 15.76 [kt CO<sub>2</sub> Equiv] (12.96%). The comparison with the

previous percentage values of both scenarios does not present significant differences in the contribution of the highest emission vehicle categories to each scenario. This situation suggests that the rate of vehicle fleet replacement toward lower emitting fuels is slow. Accelerating this rate of change would generate a much higher GHG reduction rate.

Table 11 presents the percentage distribution of GHG contributions (CO<sub>2</sub> + NO<sub>2</sub>) for each vehicle category considered in the studied scenarios. The carbon footprint variation column indicates the difference between the 2017 and 2020 contribution values for each vehicle type.

Table 11 reveals the following trends regarding the total GHG emissions of each scenario. First, in the base scenario, the carbon footprint generated by light vehicles is 79.16% and 20.54% for heavy vehicles. The 2020 emissions present GHG contributions of 81.29% and 18.42% for light and heavy vehicles, respectively. A comparison of both scenarios indicates that the contributions of heavy vehicles were reduced by 2.13%. This reduction was due to changes in the following parameters. First, the presence of heavy vehicles decreased from 7.1% in 2017 to 5.6% in 2020, for a total variation of 1.5%. Second, the travel value of the B-20 road decreased by 2.76% between the 2017 and 2020 scenarios. Therefore, the parameters vary in a range of 1.5% to 2.12%, indicating a significant influence on the global reduction of the carbon footprint (−17.03%) between the scenarios studied.

Concerning fuel type, Table 11 shows that diesel contributes the most to GHG emissions in both case study scenarios, with percentages of 99.62% (2017) and 99.09% (2020). However, it should be noted that other high emission fuels, such as gasoline, are not considered in the calculations for the province's VFCF values.

Finally, Table 12 compares the percentage variation between the NO<sub>x</sub> emission estimations of the platform proposed in this study to those found in the validation study.



**TABLE 9.** Distribution of the vehicle fleet for the 2020 emissions scenario - Barcelona province.

SRN category	DGT category	PDVF [%]	Variation [%]
Light vehicles	Cargo truck up to 3,5 t - Diesel	12.08%	-0.04%
	Van - Diesel	12.91%	0.62%
	Cars -Diesel	74.55%	-0.80%
	Cars - LPG	0.46%	0.23%
Heavy vehicles	Cargo truck on 3,5 t – Diesel	60.95%	-0.05%
	Industrial tractor-Diesel	28.35%	0.38%
	Bus - Diesel	9.96%	-0.42%
	Bus - CNG	0.74%	0.08%

**TABLE 10.** Operational carbon footprint of the B-20 road in the studied scenarios.

Vehicle category	Base scenario [kt CO <sub>2</sub> ]	2020 scenario [kt CO <sub>2</sub> ]
Cargo truck up to 3,5 t - Diesel	16.86	14.74
Van-Diesel	17.24	15.76
Cars -Diesel	82.17	68.24
Cars – LPG	0.07	0.38
Cargo truck on 3,5 t - Diesel	22.84	16.76
Industrial tractor-Diesel	3.44	2.59
Bus-Diesel	3.89	2.74
Bus-CNG	0.02	0.36
Total Emissions (kt)	146.53	121.58

The percentage of tolerance accepted in the emission estimation assessments depends on the following parameters [77]–[87]: (1) Type of fuel: This case study shows that diesel was the dominant fuel in the estimations. (2) Type of pollutant: The NEI does not consider specific uncertainty values for NO<sub>x</sub>. To address this, the lowest recommended uncertainty value (most demanding) is considered, which is associated with CO<sub>2</sub>. (3) Main estimation variable: It must be specified whether emissions are estimated based on fuel consumption or on the fuel carbon content. This proposed platform requires using fuel consumption as the main estimation value. According to these parameters, the tolerance selected in the reference study was 5%.

The results in Table 11 show that the differences between the results of the reference case and the proposed simulation are lower than 3% in both studied scenarios (specifically, 2.72% and 0.88%). These differences are explained by the following reasons: (1) Tier level used: The proposed platform uses emission factors associated with the TIER 1 level instead of the TIER 3 emission factors used in the validation study. (2) Statistics to estimate the emissions of the 2020 scenario: On the one hand, the vehicle fleet data used by the authors to estimate the emissions by 2020 were based on real information extracted from the Directorate-General of Traffic in Spain. On the other hand, in the case of the validation study, the data from the vehicle fleet were obtained from the

**TABLE 11.** Percentage distribution of the contribution of the operational carbon footprint on the B-20 road.

Vehicle category	Base scenario [%]	2020 scenario [%]	Carbon footprint variation [%]
Cargo truck up to 3,5 t -Diesel	11.47%	12.09%	0.62%
Van-Diesel	11.73%	12.92%	1.19%
Cars -Diesel	55.91%	55.96%	0.05%
Cars – LPG	0.05%	0.32%	0.27%
Total light vehicles	79.16%	81.29%	2.13%
Cargo truck on 3,5 t - Diesel	15.54%	13.75%	-1.79%
Industrial tractor-Diesel	2.34%	2.12%	-0.22%
Bus - Diesel	2.65%	2.25%	-0.40%
Bus – CNG	0.01%	0.30%	0.28%
Total heavy vehicles	20.54%	18.42%	-2.13%

**TABLE 12.** Comparison of results - proposed platform vs validation study.

Studies	Base scenario [t]	2020 scenario [t]
Platform proposed	370.32	315.17
Validation study	360.53	317.95
Variation [%]	-2.72	0.88

estimations based on the information of previous years (specifically of 2017).

The validation of the outcomes of this case study has been hard to make because the literature does not present studies with similar features to our case study.

## VI. CONCLUSION

This study proposes a platform that determines the operational exhaust emissions on different roads in a specific country. The system integrates official data about road traffic and vehicle fleet from a BIM information model. This platform manages to bring the complex methods of estimation and analysis used in different NEIs to individual roads to estimate their carbon footprint. Furthermore, this platform works within the accuracy tolerances accepted by Spain's 2020 NEI.

The system integrates emission factors from the EEA/EMEP TIER 1 level into families of BIM vehicles. The traffic and vehicle fleet information is treated in Excel spreadsheets and then exported to the BIM model through nodes of the DYNAMO visual programming software. The BIM model is used to develop tables with two main objectives: (1) determining the carbon footprint by vehicle type and fuel type for the particular road under study and (2) studying the effect that vehicle restriction strategies have on operational emissions with the goal of improving the implementation of public policy.

In operational terms, this proposed platform reduces the effort necessary to calculate the emissions that are generally

required by models that use the EMEP/EEA recommendations because traffic information or road data must be input manually into software such as COPERT. The BIM model developed here can export these estimates to other interoperable software that require this information for their studies or analysis. This method also reduces data transfer times for noninteroperable emissions software.

The BIM methodology centralizes the information about traffic, vehicle fleet, and national road network emissions into a single information model. This new development facilitates the interaction of information as it flows from different national statistics databases into one calculation engine. This potential use of BIM in the study of emissions from road infrastructure expands the capacity of this method toward other types of projects and shows that its use is not only applicable to building projects.

This study estimates the operational carbon footprint of Highway B-20 in the Province of Barcelona (Spain) to validate the proposed platform. The traffic information is extracted from the SRN traffic map, while the vehicle fleet information is extracted from the DGT statistics portal (Spain). Then, the platform evaluates the impact that Barcelona's LEZ vehicle restriction program has on the carbon footprint and compares these values to the initial estimates. The LEZ program seeks to restrict the movement of certain types of vehicles within a 95 km<sup>2</sup> area around the city. The proposed platform estimated that the LEZ program reduced GHG emissions by 17.03% between 2017 and 2020. Some of these results are compared with those provided by the validation study, which also evaluates the impact of the LEZ program on the city's emissions. The comparison shows that the differences between both studies' measurements reached a maximum variance of 2.72%, which is a tolerance accepted by Spain's current NEI.

## VII. LIMITATIONS AND FUTURE WORK

The main limitation of this study is the use of an outdated traffic database, as it is based on the last version of the traffic map dating back to 2018. To address this limitation, the traffic

database will be updated in the future as soon as this information is available. Another limitation of this work refers to its scope, as it only covers exhaust emissions. Therefore, further research seeks to extend the functionalities of this proposed platform to incorporate more types of emissions, such as cold or resuspension emission types, which require the addition of more detailed properties of the BIM families. Considering these limitations and the results obtained from the methodology proposed, the following future research lines are presented:

(1) Incorporating new Tier levels: Further studies will focus on adding TIER 2 and TIER 3 levels to add new types of pollutants and to improve the accuracy of the estimations of the proposed platform.

(2) Improving the databases with emission sensors: The databases used in this study were based on annual data gathering of the road traffic and vehicle fleet. Unfortunately, this information does not enable the real-time estimation of road emissions. Therefore, the connection of the proposed platform with emission sensors will be addressed in the future.

(3) Study of new reduction emission strategies: The impact of other strategies (such as partial replacement of the most polluting vehicles with low-emissions fuels or adding taxes to highly polluting fuels such as diesel and petroleum) will be studied.

Even though the EEA's TIER 1 method is recommended on incomplete databases in terms of interpretation, terminology, and range of fuels considered, its application in this study results in a significant exclusion, which increases uncertainty in the calculations. Therefore, it is necessary to use the TIER 2 and TIER 3 methods, which capture more information about the vehicle fleet while also linking more specific fuel properties to the platform. Together, these improvements would generate even more accurate estimation scenarios.

## APPENDIX

The following abbreviations have been used into this paper:

BIM	(Building information modeling)
GHGs	(Greenhouse gases)
NEIs	(National emissions inventories)
EEA	(European environmental agency)
NFR	(Nomenclature for reporting)
PCs	(Passenger cars)
LCVs	(Light commercial vehicles)
HDVs	(Heavy-duty vehicles)
AEC	(Architecture, engineering and construction)
IPCC	(Intergovernmental panel on climate change)
CLCD	(China life cycle database)
UNFCCC	(United nations framework convention on climate change)
LPG	(Liquefied petroleum gas)
CNG	(Compressed natural gas)
VFCF	(Vehicle fleet correction factor)

ENV	(Effective number of vehicles)
TNV	(Total number of vehicles)
ETR	(Effective travel of the road)
ITR	(Initial travel road)
TF	(Traffic factor)
GWP Index	(Global warming potential index)
FC	(Fuel consumption)
RL	(Road length)
UCF	(Unitary fuel consumption)
TE	(Total emissions)
FC	(Fuel consumed)
AFV	(Amount of family vehicles)
EF	(Emission factor)
LEZ	(Low emission zone)
SRN	(Spanish road network)
DGT	(Directore-general of traffic)
PDVF	(Percentage distribution of the vehicle fleet)

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## DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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**JORGE COLLAO** was born in Santiago, Chile, in 1993. He received the bachelor's degree in construction sciences from the Pontifical Catholic University of Chile, in 2017. He is currently pursuing the Ph.D. degree in construction engineering with the Universitat Politècnica de Catalunya, Barcelona, Spain. Since 2017, he has taught undergraduate and postgraduate courses at four universities in Chile, such as the University of La Serena, National Institute of Capacitation, University Andrés Bello, and Metropolitan Technological University. These courses are focused on the use of working methodology BIM in architecture, engineering, and construction (AEC) projects in general and on the modeling, coordination, management, sustainability simulation, and validation of BIM models. In addition, he has promoted the extensive use of BIM in local industries through master classes and keynote lectures at both companies and universities. His research interests include the development of BIM applications, such as visual programming tools, BIM implementation, and BIM advanced modeling, for several stages of the project cycle life.



**HAIYING MA** received the B.Sc. and M.Sc. degrees in bridge engineering from Tongji University, Shanghai, China, in 2004 and 2007, respectively, and the Ph.D. degree from Lehigh University, Bethlehem, USA, in 2014. She worked as a Bridge Engineer at Tonghao Consulting Company Ltd., Shanghai, from 2007 to 2008. She is currently an Associate Professor at Tongji University. Her research interests include precast/prefabricated bridge structures, bridge design methods, innovative materials and structures, structure failure processes and mechanisms, structure maintenance and model updating methods, and bridge construction management.



**JOSE ANTONIO LOZANO-GALANT** is currently a Professor with the University of Castilla-La Mancha, Spain, where he teaches subjects focused on structural engineering and building information modeling (BIM). As a researcher, he leads the MA+EE research group focused on the application of BIM to structural and environmental projects applying the latest multidisciplinary technology (such as augmented reality, structural health monitoring, digital twins, and drones). He is a member of the Spanish Commission for the implementation of BIM in Spain (e.g., BIM) and he has written more than 30 indexed articles (H-index: 13).



**JOSE TURMO** was born in Spain, in 1974. He received the Ph.D. degree from the Technical University of Catalonia—BarcelonaTech (UPC), Barcelona, Spain, in 2003. He is currently a Professor with the School of Civil Engineering, BarcelonaTech, Spain, where he teaches construction engineering and bridges. His areas of expertise are construction and maintenance of concrete bridges and structures and structural system identification. His topics of interests include the structural behavior of externally prestressed concrete bridges, applications of high-performance concrete, shear strength of concrete structures, dynamics of cable suspended bridges, structural analysis of bridge construction, structural maintenance or model updating has been addressed by him, as well as the improvement of health and safety and environmental issues of bridge construction.

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