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TOWARDS BIM-GIS INTEGRATION FOR ROAD INTELLIGENT MANAGEMENT SYSTEM

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Abstract. Roads and highways are often managed by using Geographic Information Systems (GIS). However, these systems lack the level of detail that Building Information Modelling (BIM) can bring to an infrastructure management system. BM-GIS integration allows the management of information from both infrastructure and environmental points of view. This provides an overview of the infrastructure, facilitating decision-making process throughout its complete life cycle. This article shows a semi-automated process to generate the hybrid BIM-GIS model of Madrid Calle30. The model together with an external database was uploaded to an intelligent management platform that allows visualising the available documentation, assisting management, and bringing the ring-road closer to a digital twin of the infrastructure.

Keywords: BIM, GIS, infrastructure, road, modelling, facility management, intelligent management platform.

Introduction

Industry 4.0 era has become one of the most relevant topics for years within the so-called Fourth Industrial Revolution (4IR). The Architecture, Engineering and Construction (AEC) sector is one step behind other engineering fields in productivity and digitalisation can help reducing this gap. Thus, Information and Communication Technologies (ICT) have been gradually implemented, offering great benefits in the transformation of processes and safety in construction (Maskuriy et al., 2019). These technologies drive the digital transformation of construction (Cepa et al., 2023). These technological advancements have shown outstanding advantages during the design phases of the project as well as during the construction phases. However, there are significant potential benefits of applying these new technologies throughout the project life cycle (Moreno Bazán et al., 2020). Technologies such as the Internet of Things (IoT), Big Data, Virtual Reality technologies (VR) or Cloud Computing, which enrich and facilitate Facility Management (FM) decision making, generate value and maximize the available resources (Nota et al., 2021; Pavón et al. 2020b).

Building Information Modelling (BIM) has been developed in the last two decades as a methodology that collects all information about the project over its life cycle in a three-dimensional model. The application of BIM in asset FM is increasingly widespread. The BIM model has become a repository for all information about the visual power of a three-dimensional representation. Some advantages of BIM are the workplace planning during construction (Getuli et al., 2020), as-built data collection (Gunner et al., 2021; Pepe et al., 2021), asset maintenance (Yu et al., 2021), quality control (Biancardo et al., 2020b), space management (Pavón et al., 2020a; Valinejadshoubi et al., 2021), or emergency management have been published (Deng et al., 2021a; Wehbe & Shahrour, 2021). The latest research seeks to bring the BIM model closer to Digital Twin (DT) concept, through the digital model of smart building (Deng et al., 2021b; Zheng et al., 2019) that interacts with the built environment through enabling technologies such as the IoT (Fuller et al., 2020).

Interacting in real time with the built environment is still a matter of research (Pavón et al., 2020a). The application of BIM with IoT and the processing and integration of data by Big Data can automate the interactions between the physical and the digital object, creating the so-called DT (Errandonea et al., 2020; Fuller et al., 2020). This con-

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cept has been under development for some time with the maturation of the digital market. The objective was to reduce operating costs and production time in the industry, increase the productivity of an existing system, improve asset maintenance, facilitate accessibility, or create a safer work environment (Singh et al., 2021). DT represents a breakthrough in digital transformation which applies to other industries and not only to the construction field. It is part of the so-called Product Life cycle Management (PLM). It is increasingly applied in more sectors, such as smart manufacturing, building management, smart cities, healthcare or oil and gas. DT integrates multiple engineering disciplines (Qi et al., 2021). Moreover, DT is a complex system in which the main problems arise in integrating between virtual entities with real objects (Jones et al., 2020), the complexity of processing and dataflows (Tchana et al., 2019). Thus, having a DT to interact with an infrastructure is essential to optimize its FM. However, most authors approach BIM-IoT integration to monitor the built environment and only the most advanced research include its management and predictive maintenance (Deng et al., 2021b). However, most of this research has been carried out in the building sector but only few in transport infrastructure (Wu, 2020).

In the AEC industry, linear infrastructure is the work with the fewest BIM-FM studies. This type of infrastructure is characterized by its by its size and shape and how it interacts with the ground. Therefore, roads are normally managed by means of Geographic Information Systems (GIS) tools. This technology allows to visualize and exploit the information associated with each element on large areas of land. It is thus perfectly suitable for the characteristics of this type of linear infrastructure (Al-Mansoori et al., 2020; Ojo et al., 2019). The most notable recent advances range from ordinary O&M applications such as pavement condition assessment (Al-Mansoori et al., 2020; Almuhanna et al., 2018; Ojo et al., 2019), traffic management (Sajeed et al., 2021), sustainability (Chiteculo et al., 2022; Picchio et al., 2020), optimisation of transport networks (Bi et al., 2021), or the relation of the landscape to the road (Dang et al., 2019; Martín et al., 2016; Talebi et al., 2019).

Moreover, much of the information provided by Public Administrations such as maps or traffic data are also available or compatible with the formats used in GIS tools (Picchio et al., 2020; Sajeed et al., 2021). BIM-GIS integration can improve the quality and quantity information, helping decision-making for those responsible for Operation and Maintenance the infrastructure (O&M) (Abd et al., 2020; Carneiro et al., 2019) and supporting the development of sustainable built environments (Wang et al., 2019). The BIM provides detailed information on each element while the GIS provides an overall vision of the whole and the interactions with its environment (Biancardo et al., 2020c; Sharafat et al., 2021). Furthermore, ICT could be able to provide information to both models and solve some interoperability issues between the two systems (Sharafat et al., 2021). BIM-GIS has been introduced during pavement construction (Han et al., 2022), BIM modelling using LiDAR in coordination with existing geospatial information (Barazzetti et al., 2020) or even the modelling of Roman roadways using Heritage-BIM by storing the BIM model together with the GIS information layers in the cloud (Biancardo et al., 2020a). However, all these efforts have been concentrated in the combination of BIM and GIS techniques, but they lack bidirectional information flow that could imply nearing transport infrastructure closer to the DT concept.

Within the published research, great efforts are being made to search for standardised BIM-GIS integration processes (Kang, 2013; Kang et al., 2016). Various case studies have been developed, such as those mentioned above, each with their own techniques and methods, emphasising their benefits and positive aspects, so that a standardised approach is still lacking in the field of FM (Coates et al., 2022). In addition to the problems of integration and interoperability of the models, there is also the reluctance of the different stakeholders involved in the management system to adopt these integrated models (Matos et al., 2022).

The coordination of BM-GIS models enables information to be managed from the point of view of infrastructure (micro) and environment (macro) (Han et al., 2020; Roumyeh & Badenko, 2022; Zhang et al., 2020), including all data required for the FM (Sharafat et al., 2021). Therefore, BIM-GIS integration is a DT approach, bringing together the infrastructure and its environment in a single model. Some authors develop semiautomatic systems for integrating the two models using open standards (Dursun et al., 2022) or the use of standards in on-boarding processes (Clemen, 2022), although a stable two-way flow of information cannot yet be established (Zhu & Wu, 2022). In reviewing the case studies, BIM-GIS was used within the framework of the smart city concept, for example for natural disaster planning (Varfolomeev et al., 2020) or managing cultural heritage (Bazán et al., 2021; Pepe et al., 2021). This research focussed on the generation of a BIM model from GIS data to integrate into a GIS environment.

This article sought to build on existing GIS databases for the management of assets such as roads through an automatically updated BIM model. It shows a semi-automated process to generate a hybrid BIM-GIS models, detailed enough for use in the FM of an existing infrastructure. To that end, the steps to generate a Calle30 BIM model from open data, taking it to the geospatial GIS model of its environment, are shown. Additionally, an intelligent management platform will be developed to visualize the available documentation, the data in real time using IoT sensors or the information published by the Public Administrations together with the digital BIM-GIS model. It will be the key to the future DT of the highway.

1. Background and motivation

Leveraging GIS databases in road management with a BIM digital information model is a qualitative leap in O&M linear infrastructure. BIM-GIS integration improves the visualization and detail of each object without losing the overall view and interaction with its environment. However, there are still some challenges, such as interoperability between applications or visualizing a dataset. The main constraints encountered in this study are shown and discussed in this study.

1.1. Scale issue

Road management has traditionally been based on GIS systems, which are characterized by their ability to cover large areas using basic vector geometries (point, line and polygon) with data frames such as Digital Terrain Model (DTM). These 2D objects contain all the required FM data. However, they lack geometric details beyond the look of their symbology. Today, the most commercial advanced applications in the GIS industry can add 3D objects, such as ArcGIS®, QGIS® or GRASS GIS®. Nevertheless, these geometries are either basic, pyramids or polyhedrons, or they need external applications to add more specific details. It is there that the BIM methodology comes into play. A BIM model can have all the details needed, whether for road constructions such as a bridge or the drainage system, the detail of a type of traffic sign or the mechanism of installation of the tunnel.

1.2. Application interoperability

The advantages of BIM-GIS lie in the interoperability between its applications and its files. While interoperability among geometric models is resolved, mainly from BIM to GIS, but not at the semantic layer (Celeste et al., 2022). Nowadays, commercial BIM tools such as InfraWorks® or Civil 3D® in their most recent versions are able to connect with GIS applications such as ArcGIS® and vice versa. However, a standardized FM system requires the use of multiple applications, the parameterisation of their individual elements and the information associated with them. In addition, the use of these applications can be more complicated for O&M staff. Therefore, the use of these commercial tools is better suited to other phases of the life cycle, such as the planning and design of new construction.

In order to achieve further standardization, a bidirectional workflow has been developed using the most commonly used tools and databases available. Interoperability between two-way software has already been resolved and requires intermediate steps which will be discussed in the next section. But the key to interoperability lies in georeferencing. Any basic GIS object in vector format is already georeferenced and the associated non geometric information can be managed using external databases in text or spreadsheet format. The problem is the georeferencing of BIM objects as their associated information is parameterized and has a stable information flow with external databases.

1.3. File formats

Information for the FM of an infrastructure is stored in relational databases, generally in XLSX, CSV or XML format or in a more advanced format such as Structured Query Language (SQL). These formats are compatible with GIS tools and with the primary GIS format, the SHP vector file. In addition, government data are often supplied in this type of format. This format is in turn compatible with Computer Assisted Design (CAD) formats, which in turn are compatible with BIM formats. However, compatibility between GIS and BIM formats is far more limited. Although CAD maintains georeferencing as a means of communication, it is not feasible to use it, as some of the related information is being removed as part of the process, i.e., the import/export process between GIS and CAD only transfers objects geometry, not the information contained in the metadata.

At the same time, the use of open formats for each discipline, IFC (Industry Foundation Classes) and CityGML, leads to unavoidable data leakage, which is even more pronounced in major construction projects (Zhu & Wu, 2022). The main commercial applications in each industry provide the capability to import and export to the different formats. For example, more advanced GIS applications can load and operate specific BIM formats, such as RVT. In the opposite scenario, from GIS to BIM, some intermediate process is needed such as object programming. Therefore, nowadays there is already enough interoperability between applications, or some compatibility between formats.

2. Workflow

FM of a road is usually carried out by means of indicators on the road as a whole and for each specific element of the superstructure. A smart management system based on BIM-GIS integration for a stretch of the Calle 30 urban ring road in the city of Madrid, Spain, is presented below. This section is approximately 2 km long with open skies, between kilometre points 18+900 and 20+800. In each of the following sections, the steps taken are described, from data collection to the creation of an online management platform incorporating the BIM-GIS hybrid model, the data environment, the public data and the road O&M databases This is the first step to obtain the desired of DT infrastructure, which is to interact through the platform and external information in real time in the 3D model. Future research will address the reverse path, i.e., intervening in the real world from the digital model by means of IoT devices, completing the two-way information linkage of a DT. Figure 1 shows an outline of the relationships between these steps and summarizes the steps of this study.

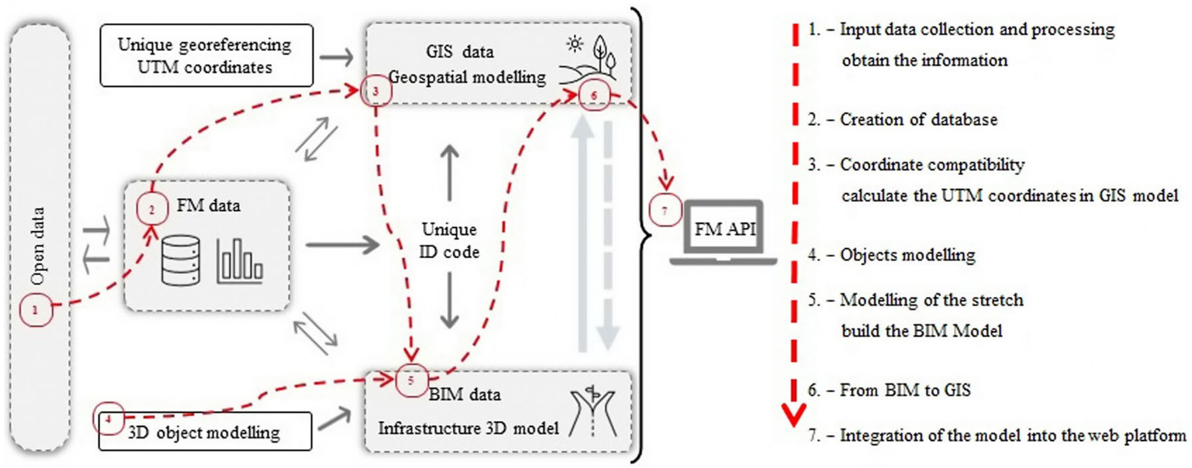


Figure 1. Research outline diagram

Four data models can be seen in Figure 1: the available data, the FM database of the infrastructure, the GIS model and the BIM model. The communication between these models is bidirectional. In this study, the path indicated by the red dotted line has been followed.

2.1. Input data collection and processing

Initial information was obtained through open government data and extensive fieldwork. These data sources are of different types and formats, although most of them were obtained from the Geoportal of Madrid City Hall (Ayuntamiento de Madrid, 2022) and based on data posted on the road authority's own website (Madrid Calle 30, 2022). Such open data is tied into the smart city concept. The more advanced the digitalisation of cities, the more data will become available. A list of the main data collected about the file format and the geometric shape of their GIS layer is presented in Table 1.

2.2. Creation of database

These data have been used to create a relational database focused on a future FM, with the information currently available and ready to be increased. For this purpose, they have been structured by using spreadsheets in XLSX format, while other formats can be used and, in the future, information will be transferred to a standardized language such as SQL. A database has been created for each of the objects on the road such as vertical signs, warning lights or pavement. Such objects were placed by an insertion point or line. Among the associated information, a field has been added to serve as a unique Identity Number (ID) for each object, being uniquely identified in the BIM model and in the GIS model. This will also be the identification field in the data bases.

Table 2 shows the structure of the database. It is divided into two parts, one related to the road platform and the other to road equipment. The structure shows the name of the created tables. The relationships between them are established by the primary key, which is the ID of the table from which they hang the rest of the tables.

Table 1. Input data, the file format and its geometry type in GIS

Input data	File format	Geometry type
city mapping	SHP/DWG	line
track layout	SHP	line
road name	KMZ	text
real-time traffic data	XML	text
traffic cameras	SHP/XML/KMZ	point
variable information panels	SHP/XML	point
vertical sign	SHP/CSV	point
road marking	DWG	line
digital terrain model	ASC	raster
building scene layer	SLPK	polyhedron
technical standards	PDF	raster
bus stops	SHP	line

Figure 2 shows an extract of the databases and the relationships between them. Although there were two main parts encompassing the databases (Table 2), these parts were not completely independent but related to each other, as shown in Figure 2. It is important to note that each database has at least one unique field, although there may be more than one. This unique field is used for two tasks. First, to uniquely identify the element. Second, to relate the element to another database that provides different information about this unique field. In this way, duplicate information is avoided, thus optimising FM.

Infrastructure FM data will be hosted in these databases but will not be added to the BIM and GIS models. This is due to the processing power. All information not relevant to the geometry of the model or the identification of each object, i.e., FM-specific information such as links, dates, maintenance and inspection reports, etc. would considerably increase the file size of the three-dimensional model. The larger the size of this file, the more hardware

Table 2a. Data base of road inventory

0.0. Road Network Management				
	0.1. Road inventory			
		1.0. Roadway		
			1.1. Carriageway sections	1.1. Alignments
				1.2. Platform
		2.0. Singular structures		
			2.1. Tunnels	2.1.0. Status report
				2.1.1. Slabs
				2.1.2. Walls
				2.1.3. Foundations
				2.1.4. Coverings
			2.2. Bridges	2.2.0. Status report
				2.2.1. Decks
				2.2.2. Piers
				2.2.3. Foundations
				2.2.4. Parapets
				2.2.5. Abutments
				2.2.6. Bearings
			2.3. Footbridges	2.3.0. Status report
				2.3.1. Decks
				2.3.2. Piers
				2.3.3. Foundations
				2.3.4. Railings
				2.3.5. Abutments
				2.3.6. Bearings
			2.4. Walls	2.4.0. Status report
			2.5. Drainage system	2.5.0. Status report
		3.0. Superstructure		
			3.1. Pavement	3.1.1. Pavement types
			3.2. Sidewalk	3.2.1. Sidewalk types
			3.3. Curb	3.3.1. Curb types
			3.4. Barriers	3.4.1. Barrier types

Table 2b. Data base of road equipment

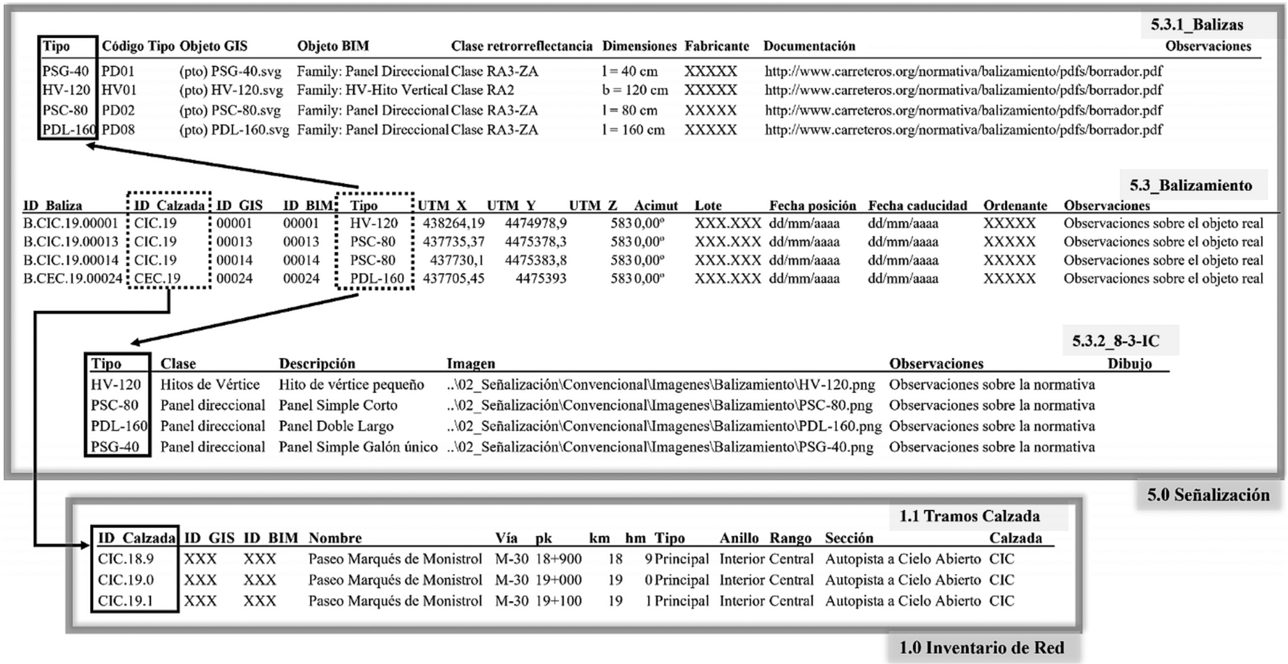
0.0. Road Network Management				
	0.2. Road equipment			
		4.0. Facilities		
			4.1. Lighting	4.1.0. Status report
				4.1.0. Luminaire type
			4.2. Ventilation	4.2.0. Status report
				4.2.1. Fume extractor types
			4.3. Firefighting system	4.3.0. Status report
				4.3.1. Fire-fighting equipment
			4.4. Drainage system	4.4.0. Status report
				4.4.1. Draining equipment
		5.0. Traffic signage		
			5.1. Vertical sign	5.1.0. Vertical sign types
				5.1.0. Guideline 8.1.-IC
			5.2. Road marking	5.2.0. Road marking types
				5.2.0. Guideline 8.2.-IC
			5.3. Traffic beacon	5.3.0. Beacon types
				5.3.1. Guideline 8.3.-IC
			5.4. Variable information panel	5.4.0. Status report
				5.4.1. Information panel types
			5.5. Traffic lights	5.5.0. Status report
				5.5.1. Traffic light types
		6.0. Traffic management		
			6.1. Vehicle counting system	6.1.0. Status report
				6.1.1. Vehicle counter
			6.2. CCTV	6.2.0. Status report
				6.2.1. Traffic cameras
			6.3. Speed controls	6.3.0. Status report
				6.3.1. Radar speed control camera
			6.4. SOS	6.4.0. Status report
				6.4.1. Emergency telephone
			6.5. Emergency exits	6.5.0. Status report
				6.5.1. Emergency exit types
		7.0. Conservation parameters		
			7.1. Gas measurements	7.1.0. Status report
				7.1.1. Gas sensor
			7.2. Noise measurements	7.2.0. Status report
				7.2.1. Noise sensor
			7.3. Environmental measurements	7.3.0. Status report
				7.3.1. Environmental parameter sensor

resources will be needed to operate it. To optimise data management and visualization of the generated model, the associated information is accessible from the web management application, not from the BIM-GIS models.

2.3. Coordinate compatibility

Each initial data had different coordinate systems. The European Terrestrial Reference System 1989 (ETRS89) is the official Spanish geodesic reference system. However, some layers were found in the European Datum 1950 (ED50) or the World Geodetic System 1984 (WGS84) amongst others. As a result, in order to use the data geographically, harmonizing their projection was required. In this case, all GIS layers have been projected into ETRS89.

Furthermore, for compatibility with BIM models with XYZ axes, the Universal Transverse Mercator (UTM) coordinate system was used. This means that fields with X, Y and Z coordinates have been added to each object in the database. To calculate these fields, the geoprocessing tools of the GIS tools were used, the DTM of the Madrid region being necessary for the calculation of the Z coordinate. For this research, the specific geoprocessing tools of the open software application QGIS according to the workflow shown in Figure 3 have been used. In the case of line-type elements, they have been identified by their origin and end points.



5.3.1_Balizas

Tipo	Código Tipo	Objeto GIS	Objeto BIM	Clase retrorreflectancia	Dimensiones	Fabricante	Documentación	Observaciones
PSG-40	PD01	(pto) PSG-40.svg	Family: Panel Direccional	Clase RA3-ZA	l = 40 cm	XXXXX	http://www.carreteros.org/normativa/balizamiento/pdfs/borrador.pdf	
HV-120	HV01	(pto) HV-120.svg	Family: HV-Hito Vertical	Clase RA2	b = 120 cm	XXXXX	http://www.carreteros.org/normativa/balizamiento/pdfs/borrador.pdf	
PSC-80	PD02	(pto) PSC-80.svg	Family: Panel Direccional	Clase RA3-ZA	l = 80 cm	XXXXX	http://www.carreteros.org/normativa/balizamiento/pdfs/borrador.pdf	
PDL-160	PD08	(pto) PDL-160.svg	Family: Panel Direccional	Clase RA3-ZA	l = 160 cm	XXXXX	http://www.carreteros.org/normativa/balizamiento/pdfs/borrador.pdf	

5.3_Balizamiento

ID Baliza	ID Calzada	ID GIS	ID BIM	Tipo	UTM X	UTM Y	UTM Z	Acimut	Lote	Fecha posición	Fecha caducidad	Ordenante	Observaciones
B.CIC.19.00001	CIC.19	00001	00001	HV-120	438264,19	4474978,9	583	0,00º	XXX.XXX	dd/mm/aaaa	dd/mm/aaaa	XXXXX	Observaciones sobre el objeto real
B.CIC.19.00013	CIC.19	00013	00013	PSC-80	437735,37	4475378,3	583	0,00º	XXX.XXX	dd/mm/aaaa	dd/mm/aaaa	XXXXX	Observaciones sobre el objeto real
B.CIC.19.00014	CIC.19	00014	00014	PSC-80	437730,1	4475383,8	583	0,00º	XXX.XXX	dd/mm/aaaa	dd/mm/aaaa	XXXXX	Observaciones sobre el objeto real
B.CEC.19.00024	CEC.19	00024	00024	PDL-160	437705,45	4475393	583	0,00º	XXX.XXX	dd/mm/aaaa	dd/mm/aaaa	XXXXX	Observaciones sobre el objeto real

5.3.2_8-3-IC

Tipo	Clase	Descripción	Imagen	Observaciones	Dibujo
HV-120	Hitos de Vértice	Hito de vértice pequeño	..\02_Señalización\Convencional\Imagenes\Balizamiento\HV-120.png	Observaciones sobre la normativa	
PSC-80	Panel direccional	Panel Simple Corto	..\02_Señalización\Convencional\Imagenes\Balizamiento\PSC-80.png	Observaciones sobre la normativa	
PDL-160	Panel direccional	Panel Doble Largo	..\02_Señalización\Convencional\Imagenes\Balizamiento\PDL-160.png	Observaciones sobre la normativa	
PSG-40	Panel direccional	Panel Simple Galón único	..\02_Señalización\Convencional\Imagenes\Balizamiento\PSG-40.png	Observaciones sobre la normativa	

5.0 Señalización

1.1 Tramos Calzada

ID Calzada	ID GIS	ID BIM	Nombre	Vía	pk	km	hm	Tipo	Anillo	Rango	Sección	Calzada
CIC.18.9	XXX	XXX	Paseo Marqués de Monistrol	M-30	18+900	18	9	Principal	Interior	Central	Autopista a Cielo Abierto	CIC
CIC.19.0	XXX	XXX	Paseo Marqués de Monistrol	M-30	19+000	19	0	Principal	Interior	Central	Autopista a Cielo Abierto	CIC
CIC.19.1	XXX	XXX	Paseo Marqués de Monistrol	M-30	19+100	19	1	Principal	Interior	Central	Autopista a Cielo Abierto	CIC

1.0 Inventario de Red

Figure 2. Extract of the databases and relations between them

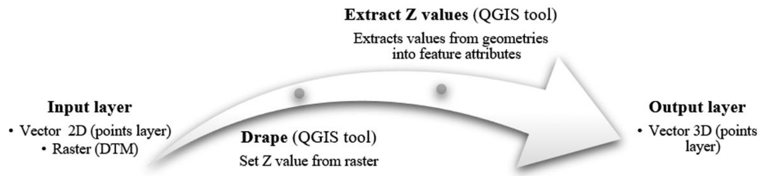


Figure 3. Workflow to calculate the Z coordinate

2.4. Objects modelling

All existing roadway components were modelled by using Autodesk Revit® families. Over 100 families have been developed, with over 100 family types. All these objects range from the pavement, protection barriers, streetlamps, variable information panels or traffic cameras. In addition, all the existing vertical signs and road markings were modelled. To this end, the signage defined in the Spanish standard, instructions 8.1 IC (Ministry of Development, 2014) and 8.1 2C (Ministry of Development, 2020) and their annexes have been digitalized.

All the elements were developed as standard as possible to create a directory, with the aim of allowing to extrapolate them to other road projects. However, not all the objects could be generated with the Autodesk Revit® modelling tools, so other more specific drawing tools such as AutoCAD® or SketchUP® were used to generate those elements.

A text parameter was added to all the objects and will be the ID. In the case of vertical signs or beacon, visibility parameters have been included to aid in the automation of the 3D model generation process, such as whether the support pole exists or not, its height or the text of the signs. In the case of vertical signs or traffic marks, other parameters have been added to assist in the automation of the process of generating the complete BIM model. For example, text type parameters have been added to add the text of these signs.

2.5. Modelling of the stretch

The development of the model was carried out with Autodesk Revit®. This was not only performed given that this tool was the most common software in the industry. Some other considerations were made for this decision that suppose requirements for its future use:

- The segmentation of the model by parametric element allows the reuse of these 3D objects for other infrastructure.
- The infrastructure serving as example, the Madrid Calle 30 highway, is a ring-shaped infrastructure, 30 km long, so its geographical extension did not exceed the working limits of this software.
- The Calle 30 shape, which is composed of tunnels and open-air segments, with several bridges, footbridges, and large nodes with other highways. Each of these elements were in themselves a project. The union of all of them forms Calle 30 and each of them requires a specific processing and must be assembled later.
- The compatibility with GIS applications. The most used tool for this area is ArcGIS® and it is capable

to loading RVT files while preserving their associated information. It also offers greater visualization options for the models and their environment. It also enables the generation of simple web applications or the possibility by its own applications through open libraries.

The final development of the model was automated by means of Dynamo® visual programming. Several programmes relating to road infrastructure management and modelling were developed. One program was created to read the SHP vector file along with the road alignment. From this line, the floor, which represents the pavement, could be drawn. To do this, the width of the platform was added, as a field of the related database. It was also necessary to correct the internal orientation of the line, as the interpretation of its system of internal coordinates may be incorrect. Also, the floor may not be drawn because the Z-axis was not properly interpreted. In this case, it was represented by sections between the subdivisions of each mileage point as an independent line of about 100 metres, both in the SHP file and in the database, so this was how it was drawn in the BIM model. This process is shown with the minimum steps in Figure 4.

This process can be simplified by reading the database in text format, but in this case, much detail is lost. By using this method, the section was defined by the UTM coordinates of its origin and end points. However, a straight line was generated and the curvature of the line alignment in the SHP file was lost. This geometric error can be mitigated by splitting each segment into this number of sub-segments, increasing the number of entries in the database. Moreover, the longitudinal slope of each section must be entered manually, as the software does not allow access to this parameter during automation. In this case it will only be necessary to apply a slope and define the final end elevation, as the initial end elevation will have been defined during automation.

By contrast, road assets were placed at their point of insertion. This was identified by its UTM coordinates, and its family type defined according with the corresponding rows in the XLSX database. In addition, these elements must be oriented, so an additional field was added to the database with the angle of the element relative to the North. This program also reads the rest of the automated parameters, such as visibility or text for vertical sign. Figure 5 shows this process with the minimum steps.

Also, the reverse program shown in Figure 6 were performed. From the Revit® drawing it produces a XLSX file with the unique ID information, the UTM coordinates, the angle in relation to the North and the associated minimum parameters of the selected families. Figure 7 shows the information exported by this program.

Note that the "ID" parameter is the identification specific to our management system, while the "ID_BIM" parameter is the identification that the BIM modelling software automatically generates for each object. Similarly, the GIS software also generates its own "ID_GIS" identification codes. Both "ID_BIM" and "ID_GIS" codes are internal to their respective applications.

A correction of the UTM coordinates is required in these three programs, due to the extension limitation of the drawing in Autodesk Revit®. This limit with graphical rendering is for a circumference of 16 kilometres from the internal origin of the model. This was solved by positioning the "Project Base Point" at the centre of the ring representing Calle 30, and making it coincide with the "Internal Origin Point" of Revit®. In addition, localising the project from the beginning by using the "Survey Point" where the coordinates are known was required. This correction was performed by subtracting from the UTM coordinates on the X and Y axes of each element an amount equal to the value of the UTM coordinates on these two axes of the "Project Base Point".

Finally, it was required to manually place some linear elements, such as road markings or protection barriers. However, these elements may be generated automatically with the programs described above, as long as the original databases are correctly defined. Furthermore, it was also needed to manually model certain specific areas, such as connections with other roads where the platform did not have a regular geometry. Figure 8 shows the result of a section of the model under study.

2.6. From BIM to GIS

The environment model was developed in ArcGIS®, generating a 3D scene. To do this, a "building layer" was built from the BIM model in Revit®, which contains the basic information associated to each element. In this case, the "ID" parameter is the only associated data, as all the information is stored in the external database.

Nowadays, current versions of ArcGIS Pro are able to import and operate with files in RVT or DWG formats. However, it is important to consider the version of the software version being used, as there may be incompatibilities. For example, this project started modelling with Revit 2020 whose files are fully interoperable with ArcGIS Pro 2.9 software. However, it later switched to Revit 2023, whose files are not supported by that version of the GIS software. To maintain the workflow, it is necessary to use the open IFC format, which is compatible with both tools and facilitates interoperability between BIM and GIS.

This format results in a loss of associated information. However, each element is encoded with its identity parameters "ID". The parameters auto-generated by each tool are always kept invariant during the processes between applications. Therefore, it will always be possible to relink such documentation at any part of the process as it will always be associated from the external database.

Once the BIM model has been imported, it has been converted into SLPK or "building layer" format, which is the specific format for this type of files in this GIS application. Complementary GIS information has been added to this scene in order to improve the visualization and interpretation of the environment, such as the DTM or city buildings. Figure 9 shows the visual result of the hybrid BIM-GIS model.

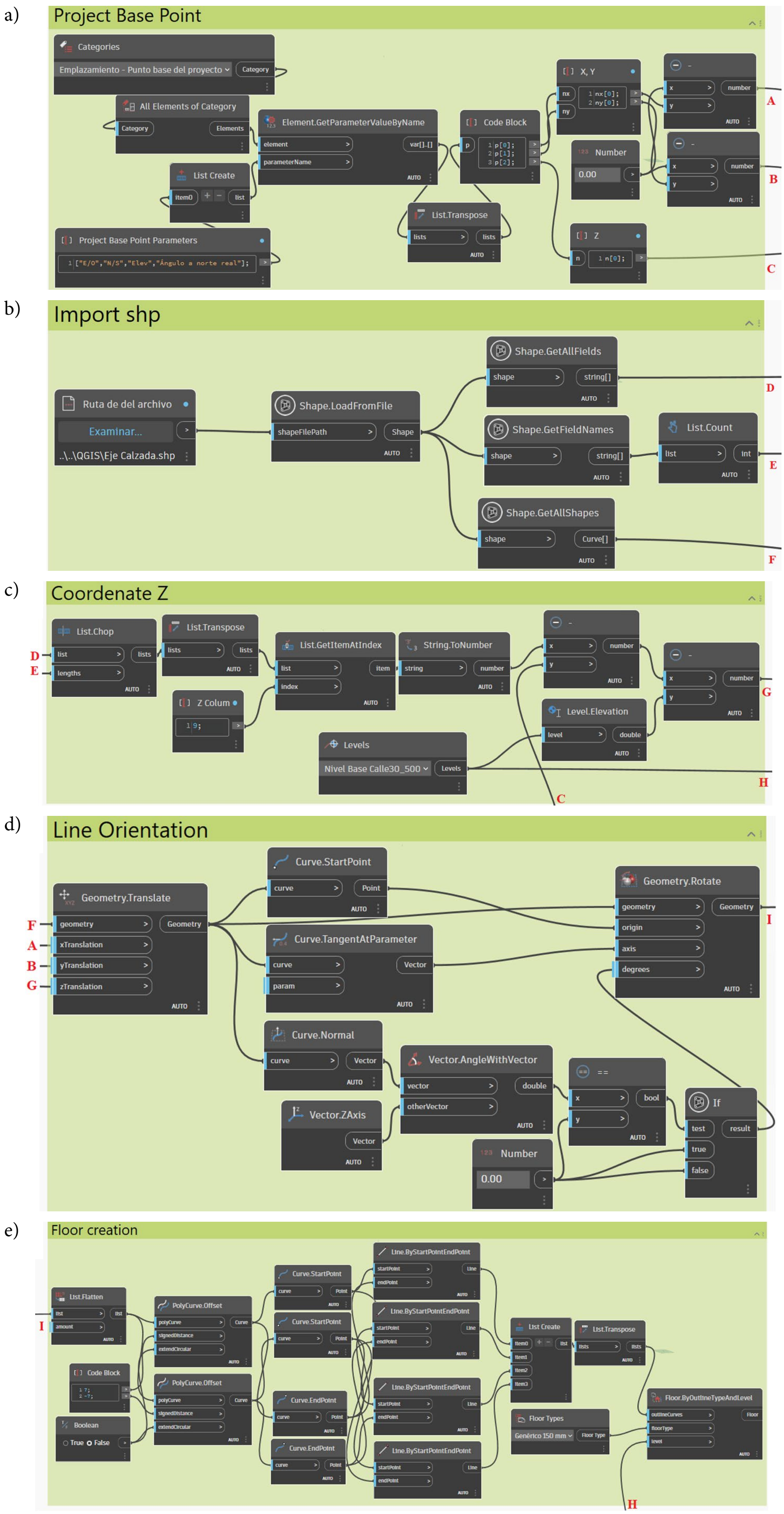


Figure 4. Import shape files to print pavement

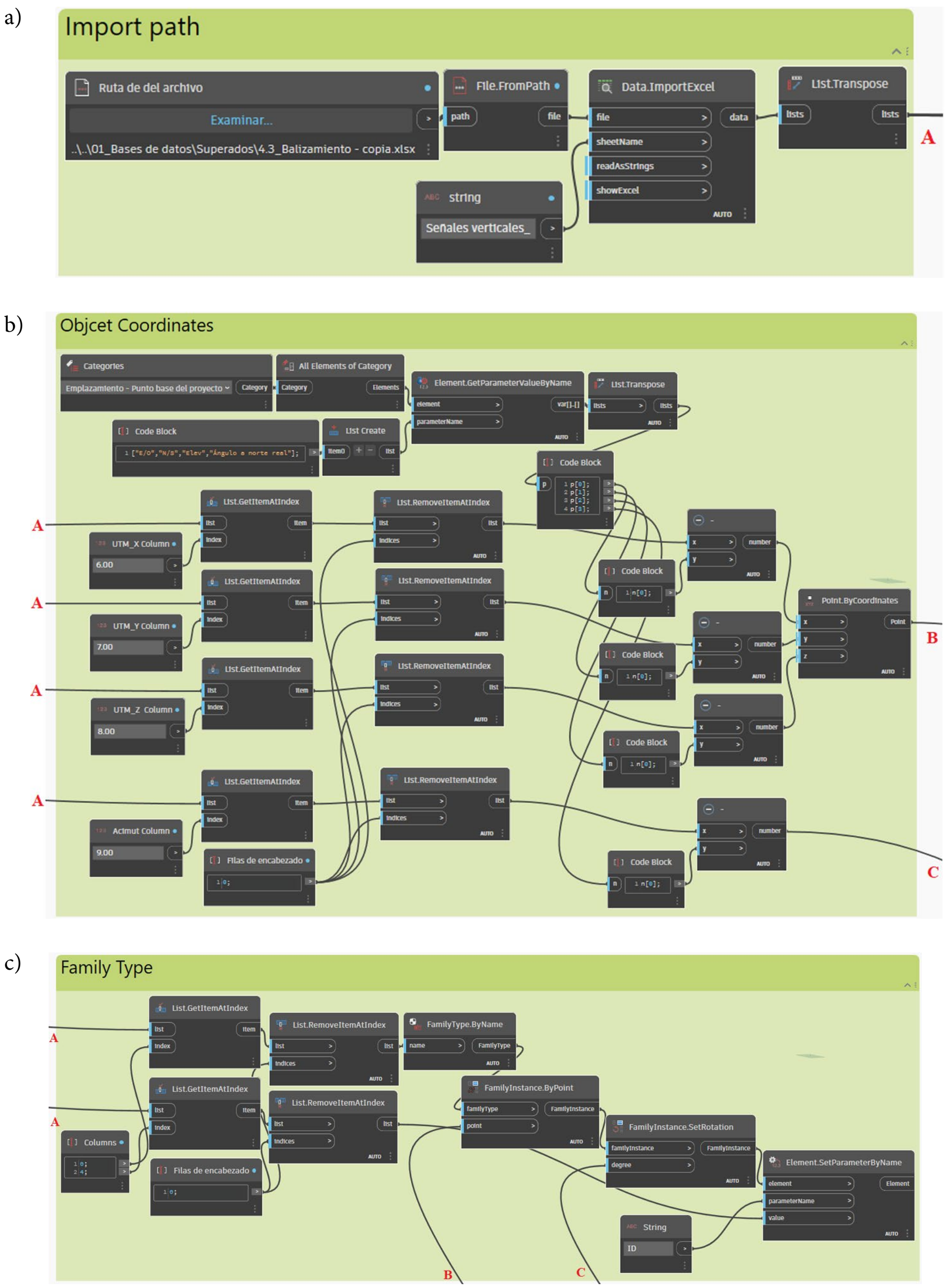


Figure 5. Import database to print family type

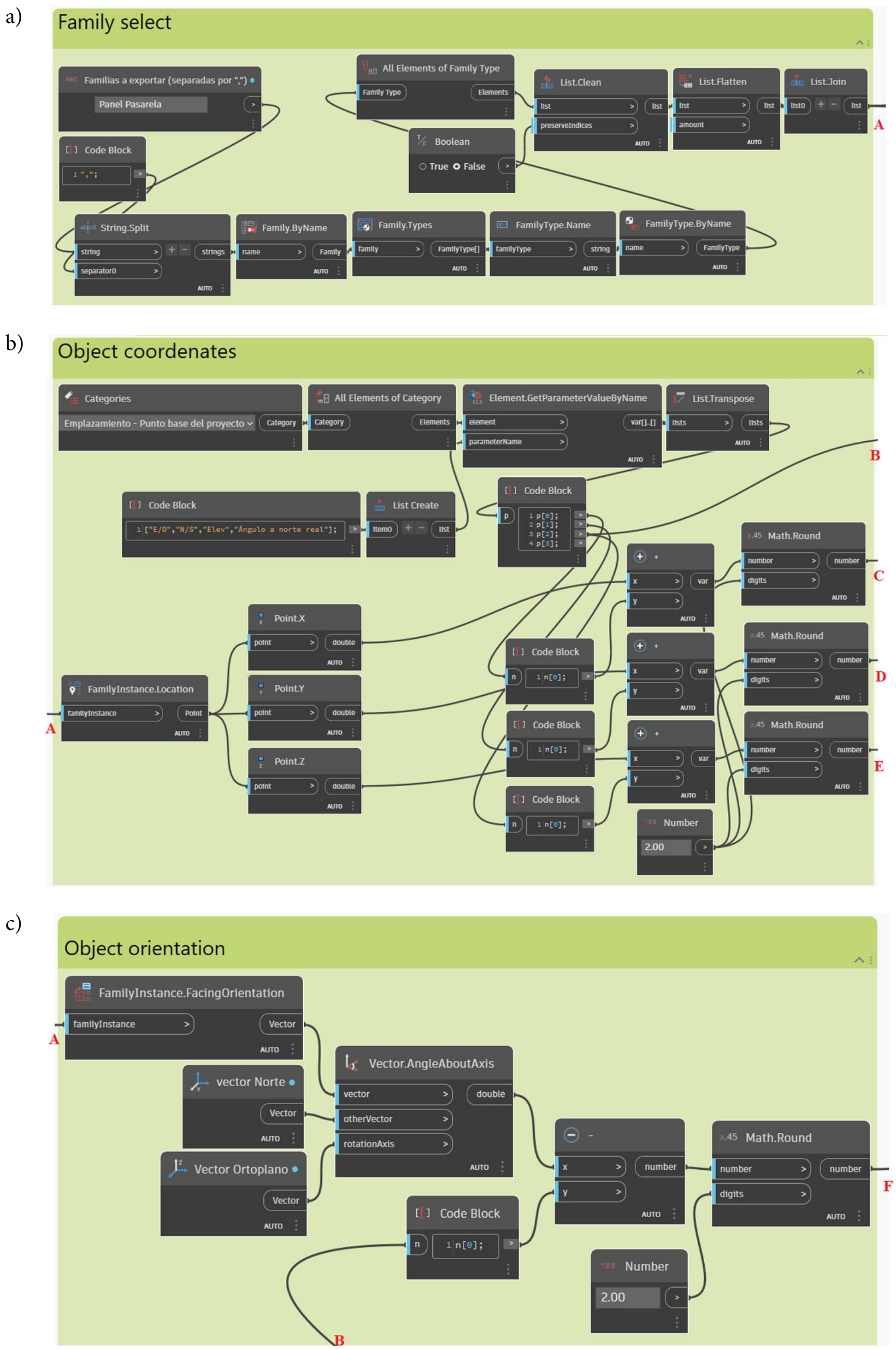


Figure 6. *To be continued*

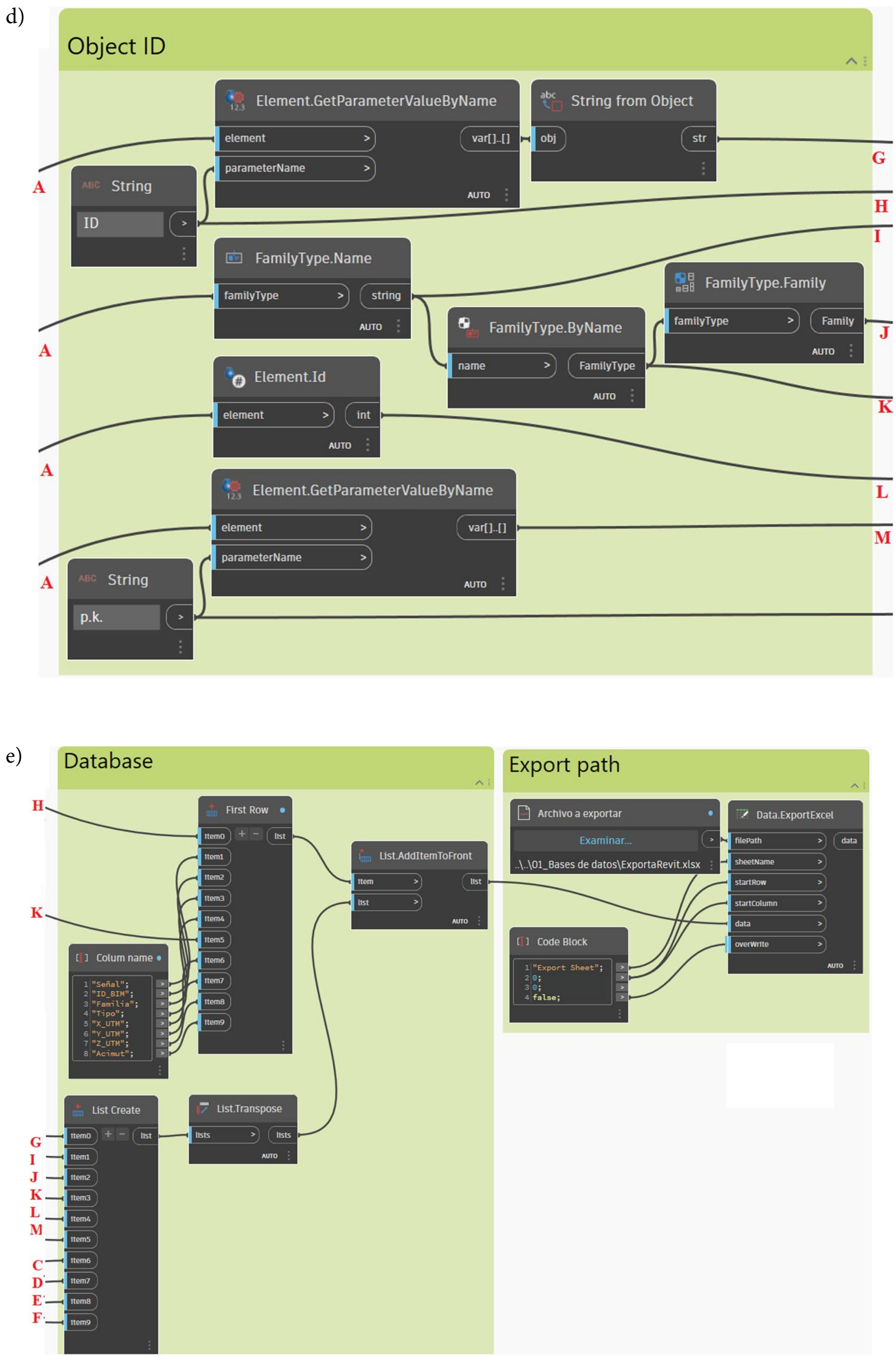


Figure 6. Export family type to database

ID	Señal	X_UTM	Y_UTM	Z_UTM	Acimut	Familia	ID_BIM
19.CIC.0018	CH-75	437406,35	4476188,37	589,28	0,00	Family: CH-75	625871
19.CIC.0019	CH-75	437405,29	4476193,64	589,21	270,00	Family: CH-75	625874
19.CIC.0020	CH-75	437404,24	4476198,81	589,14	0,00	Family: CH-75	625877
19.CIC.0021	CH-75	437279,60	4476332,55	597,08	0,00	Family: CH-75	1027991
19.CIC.0022	CH-75	437278,20	4476334,18	597,05	0,00	Family: CH-75	1027994
19.CIC.0023	CH-75	437277,09	4476335,73	597,03	0,00	Family: CH-75	1027997
19.CIC.0024	02_PSC-80	437491,46	4475832,44	588,70	348,00	Family: Panel Direccional	625676
19.CIC.0025	02_PSC-80	437493,60	4475832,90	588,75	348,00	Family: Panel Direccional	625679
19.CIC.0026	02_PSC-80	437738,73	4475374,15	588,56	302,00	Family: Panel Direccional	1024519
19.CIC.0027	02_PSC-80	437733,49	4475379,24	588,63	302,00	Family: Panel Direccional	1024566
19.CIC.0028	02_PSC-80	437727,90	4475385,41	588,72	302,00	Family: Panel Direccional	1024584
19.CIC.0029	02_PSC-80	437723,26	4475390,84	588,79	302,00	Family: Panel Direccional	1024592
19.CIC.0030	02_PSC-80	437718,88	4475395,95	588,86	302,00	Family: Panel Direccional	1024602
19.CIC.0031	02_PSC-80	437713,22	4475403,48	588,95	302,00	Family: Panel Direccional	1024612
19.CIC.0032	02_PSC-80	437501,94	4475750,04	589,13	302,00	Family: Panel Direccional	1025124
19.CIC.0033	02_PSC-80	437497,73	4475760,08	589,08	302,00	Family: Panel Direccional	1025287
19.CIC.0034	02_PSC-80	437493,95	4475771,01	589,04	302,00	Family: Panel Direccional	1025301
19.CIC.0035	02_PSC-80	437491,00	4475780,19	589,00	302,00	Family: Panel Direccional	1025313
19.CIC.0036	02_PSC-80	437385,01	4476370,62	587,61	356,42	Family: Panel Direccional	1028366
19.CIC.0037	02_PSC-80	437382,38	4476350,93	587,92	356,42	Family: Panel Direccional	1028422
19.CIC.0038	02_PSC-80	437380,76	4476334,01	588,01	356,42	Family: Panel Direccional	1028434
19.CIC.0039	02_PSC-80	437379,84	4476317,70	588,09	356,42	Family: Panel Direccional	1028446
19.CIC.0040	02_PSC-80	437379,55	4476302,90	588,17	356,42	Family: Panel Direccional	1028458
19.CIC.0041	02_PSC-80	437379,40	4476289,66	588,24	356,42	Family: Panel Direccional	1028472
19.CIC.0042	02_PSC-80	437379,58	4476274,66	588,32	356,42	Family: Panel Direccional	1028488
19.CIC.0043	02_PSC-80	437380,38	4476261,40	588,39	356,42	Family: Panel Direccional	1028498
19.CIC.0044	02_PSC-80	437382,39	4476243,86	588,50	356,42	Family: Panel Direccional	1028512
19.CIC.0045	02_PSC-80	437384,76	4476229,84	588,69	356,42	Family: Panel Direccional	1028524
19.CIC.0046	04_PSL-160	437831,07	4475314,50	587,63	309,22	Family: Panel Direccional	625658
19.CIC.0047	04_PSL-160	437410,76	4476200,59	589,14	0,00	Family: Panel Direccional	625880
19.CIC.0048	04_PSL-160	437417,73	4476207,30	589,07	0,00	Family: Panel Direccional	625883
19.CIC.0049	04_PSL-160	437424,30	4476211,67	589,03	0,00	Family: Panel Direccional	625886
19.CIC.0050	04_PSL-160	437707,96	4475384,46	588,84	146,00	Family: Panel Direccional	1024958
19.CIC.0051	04_PSL-160	437714,69	4475377,09	588,74	146,00	Family: Panel Direccional	1024975

Figure 7. Extract of data base export

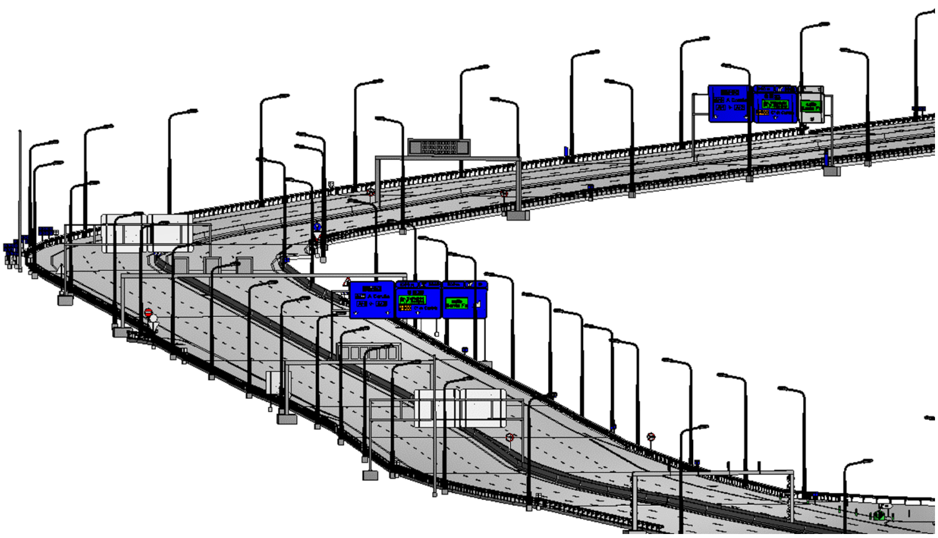


Figure 8. Extract of the 3D model of the study section

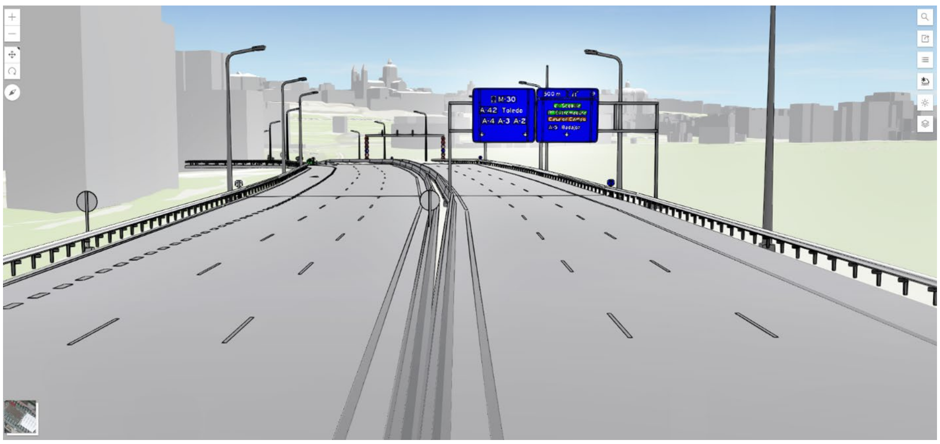


Figure 9. Extract of the hybrid BIM-GIS model

2.7. Integration of the model into the web platform

Interoperability is an essential aspect for the actual implementation of all the developments shown in this article. The generated model has a large number of potential benefits. The three-dimensional visualisation of all the elements, obtaining exact location parameters or the incidents recording of the different objects are examples of some of them. However, the functionalities and benefits increase exponentially if greater accessibility and interoperability of the three-dimensional model is achieved. For example, the incorporation of technologies such as the IoT, Cloud Computing or Big Data will increase the potential users of the three-dimensional model.

For this reason, it was decided to develop an intelligent management platform, with total accessibility from any device and with the capacity to implement the new technologies together with the three-dimensional model generated. Real-time traffic information, visualisation of official data from the administration, synchronisation with more standard management tools such as Excel or CAD were some of the new features that were incorporated by means of this platform.

2.7.1. Technical details of the platform

The intelligent management platform consisted of two main parts, namely FRONTEND and BACKEND. First, the FRONTEND was based on HTML, TypeScript and CSS programming languages for the display and behaviour of the web page. This page consisted of the programming to have a responsive behaviour before the modifications of the screen widths. Therefore, its visualisation is guaranteed for any device, including smart phones. Second, the BACKEND was based on the Python programming language. This part of the platform guaranteed user management and hosts the required Application Programming Interfaces (APIs) enabling to obtain data from different sources. In turn, the SQL database was managed by the BACKEND of the platform.

2.7.2. Workflow

The model elements were incorporated into the platform by Type Script language. The implementation of this language in the project makes the developments highly accessible and interoperable. In addition, it opened up the possibility of interacting with much more data that does not necessarily have to be from the model. Other data such as data from public transport systems and real-time traffic information are some examples.

The workflow followed to achieve the visualisation of the three-dimensional model made on the platform is shown in Figure 11. Primarily, the platform hosts the secret key of the ArcGIS® account needed to access to Java Script libraries for FRONT programming. These credentials were received by the ArcGIS® API. If the verification is correct, the platform proceeds to generate the 3D visualisation using the "unique id". To render this scene or view, the platform has to indicate in which FRONT container this visualisation will be located. If all the steps have been followed correctly, the visualisation will be achieved without any problem as it is shown in Figure 10.

Figure 11 shows the workflow required to visualise other types of data that do not originate in the generated model but are external to the model itself. The data visualised are the sections and bus stops of the EMT (*Empresa Municipal de Transportes*). The procedure was similar to the explained above, but with some small differences. The first step was similar to the previous one, the verification of the ArcGIS® online user credentials. Once this barrier was overcome, a unique identifier was not given, but the platform proceeds to create a map. This map needs an initial latitude, initial longitude, initial zoom and the FRONT container in which it will be rendered. Once the map was created, the stops layer and the sections layer are created and implemented into the map. These layers can be shown or hidden in the platform without any inconvenience, as shown in Figure 11.

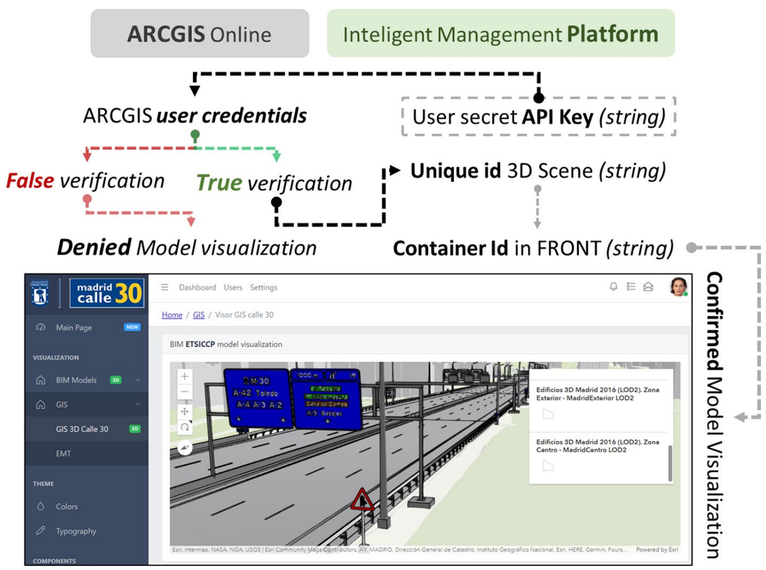


Figure 10. GIS Three-dimensional visualization on intelligent management platform

Figure 11. Public transports routes visualization on the intelligent management platform

2.7.3. Platform possibilities and future implementations

The possibility of accessing all these functionalities from any device and without the need for any prior pre-installation, represents a step forward in terms of attracting potential beneficiaries of the model. The lack of interoperability and the large initial outlay for the use of this type of tools have been and continue to be one of the main barriers to their use. Through these advances, users will be able to access GIS or BIM functionalities without the need for special hardware or the purchase of the respective licences. In addition, the platform provides great versatility in terms of data handling, eliminating the rigidity of use of commercial software. Given the full programming of the entire platform, any new functionality can be implemented. For example, reading of managing spreadsheets, implementation of sensor reading, report generation or predictive maintenance are some examples of those from the common management tools. Regarding spreadsheets implementation, a new functionality has been developed. An example is provided in Figure 12, where a spreadsheet related to beaconing is imported into the web platform. In that case, parameters like beacon, roadways, BIM and GIS identifiers with UTM coordinates are loaded into the system and stored in the relevant databases. As it is shown in Figure 12, the user will select the spreadsheet and the data will be handled firstly by the Frontend, and secondly by Backend in order to achieve the data saving into the Structured Databases. Once the data is saved, the information is prompted into the Frontend of the platform.

3. Discussion and future developments

BIM and GIS are two data modelling systems that are graphically represented at different scales, respectively at the building and environment levels. Consequently, they complement one another perfectly, giving an overview of the built environment, ease decision-making and optimise the resources available in the management of infrastructure covering large areas of land, such as roads, or having a bearing on their landscape, such as a dam. O&M activities in this type of infrastructure have historically been carried out by GIS with the storage of information in other types of formats, with the resulting loss of information. The visualization quality of GIS models has improved greatly over the last decade, including the possibility of 3D viewing. However, they are composed of simple and indivisible geometric shapes, which can be adapted by means of images. Therefore, these models provide great reality, but they are empty volumes that lack the details to perform a correct FM.

On another note, BIM enables the development of models with a high level of detail, as necessary for each object. However, within BIM there are different design tools that allow the modelling of linear infrastructure in its environment. Some of these commercial tools, such as InfraWorks® or Civil3D®, allow different design alternatives to be obtained with all the documentation required during the construction phase and are also georeferenced. For example, from the axis of a road, the entire model can be generated, with a special emphasis on the platform. Additionally, these tools allow a bidirectional workflow with traditional GIS tools, such as ArcGIS®, and their file formats. However, these applications do not produce detailed 3D parametric objects. These objects bring greater realism to digital models and, above all, allow to associate all the non-geometric information associated with each element. This becomes more relevant within the FM of existing infrastructure, such as roads, where road equipment or pavement condition becomes more relevant. In addition,

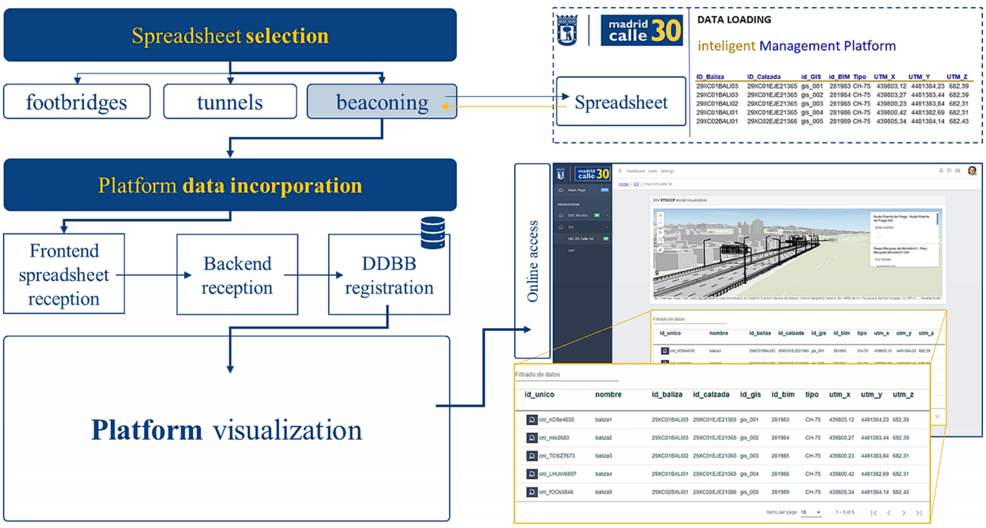


Figure 12. Spreadsheet data loading to intelligent web platform

roads are a collection of unique structures, such as bridges and tunnels, even more so in an urban environment. These structures are in themselves small BIM models, with more typical building elements.

This study chose the modelling of part of an existing infrastructure in Autodesk Revit®. The road stretch was 2 kilometres long on two carriageways of the Calle 30 ring-road. A sufficiently detailed 3D model has been built by a semiautomated process to generate geometry from existing data in SHP format or stored in spreadsheets. However, the use of this software causes some problems, mainly in the georeferencing of the model and its elements. As a solution, all GIS layer projection systems have been unified at UTM coordinates, according to ETRS89. A DTM was used to calculate the Z coordinate and the orientation of each element was calculated using GIS operators for its correct position in the BIM model. This semi-automated process by using Dynamo® allowed a useful model to be generated, optimizing resources, and reducing modelling time. However, it required a repository with the assets that make up the highway equipment. In this case, over 100 families with more than 100 different types were performed for the 2 km stretch of the ring-road.

In addition, external databases were developed in XLSX format. This database included the remaining supporting information. In these external databases, a parameter served as an identity code or a unique ID for each object has been created. This code was used to identify each object in the BIM and GIS models, and it is the only associated parameter in these models. By maintaining the rest of the information hosted externally, it is possible to reduce the weight of the model files, improving the efficiency of O&M tools. There is a large amount of public information, accessible through GIS tools such as vertical sign, traffic counters or traffic cameras. This information was used as a data source and served as supplementary documentation for the digital model.

This model contained all the information for O&M. The hybrid BIM-GIS model of the infrastructure is sufficiently realistic to benefit from the visualization of the BIM model in its geospatial environment. The semi-automated modelling process based on minimal open-source data has succeeded in creating an environment of unique objects parameterised for FM. In addition, all the information hosted in the external databases is fully accessible from the developed intelligent management platform.

The development of a database updated in real time by using connected IoT devices that can interact automatically with the virtual model will continue. All of this will be accessible and editable from a management application easy to use by road maintenance engineers and technicians. These steps will move the virtual model closer to the real model, through two-way communication between the two environments until the DT infrastructure is reached. These steps will bring the virtual model closer to the real model, with bi-directional communication between the two environments until the DT infrastructure is reached.

Conclusions

This study proposed a semi-automated process for a hybrid BIM-GIS model by using open data and serving as case study on the Calle 30 first ring-road of Madrid. In addition, an external database was created to provide information to the model and an application to support its FM. The following conclusions were reached in this study:

- A hybrid BM-GIS model allows information management from an infrastructure and environmental point of view. This allows for an overview of the infrastructure, enabling decision-making throughout its lifecycle.
- Geometric integration among BIM-GIS models has nowadays been passed. There are several commercial applications which can establish bidirectional communication between the two systems. However, in order to maintain a complete integration of geometric and non-geometric information, other BIM parametric modelling software is required, where the communication between applications is more complex.

– The development of a simple BIM-GIS model that is useful for the facility management (FM) of linear infrastructure can be automated from some basic data. It concerns the geolocation of the elements in the known coordinates XYZ and their orientation. In addition, there is a need to develop libraries of simple parametric elements with which to build the model.
– BIM-GIS models can be powered by using external databases where big data can be stored and updated in real time. For this purpose, each element of the model is identified by a unique identification code. These databases are the first step towards implementing new ICTs. Furthermore, for urban infrastructure cases, the information available may be even more extensive due to the digital transformation of the cities into Smart Cities.
– The development of the intelligent management platform that allow the virtual model to be visualised and permit interaction with the databases, is the first approach towards the implementation a co-management system. Once the bidirectional communication to the real environment is established, it will result in the generation of DT of the infrastructure and its environment that optimizes the FM resources.
– The platform provides great versatility in terms of data handling, eliminating the rigidity of use of commercial software. Thanks to the full programming of the entire platform, any new functionality can be implemented. For example, reading of spreadsheets that are commonly used until now for management, implementation of sensor reading, report generation or predictive maintenance.

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Author contributions

Conceptualization, M. G. A.; Data curation, J. J. C.; Formal analysis, J. J. C., R. M. P., M. G. A. and P. C. L.; Investigation, J. J. C , R. M. P. and P. C. L; Methodology, J. J. C, R. M. P., M. G. A. and P. C. L. and J. R. T.; Resources, M. G. A.; Software, J. J. C , R. M. P., M. G. A. and P. C. L.; Supervision, M. G. A.; Validation, M. G. A. and J. J. C.; Visualization, R. M. P. and M. G. A.; Writing – original draft, J. J. C., R. M. P., M. G. A. and P. C. L.; Writing – review & editing, J. J. C. and M. G. A. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

The authors declare no conflict of interest

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