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Review

Quantitative and Qualitative Analysis on the Integration of Geographic Information Systems and Building Information Modeling for the Generation and Management of 3D Models

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Abstract: 3D virtual management is a topic of growing interest. The AEC industry is undergoing a real revolution because of the technological changes that are taking place. Synchronized 3D visualization is one of the tools being deployed at an accelerated pace. This, together with collaborative work, contributes to optimal management for all stakeholders. The integration of geographic information systems and building information modeling and heritage BIM is one of the most innovative concepts; it enables the generation of collaborative, fluid systems. The objective of this research is to identify the most significant technological developments and potential applications of the aforementioned integration. For this purpose, after a bibliographic consultation (26,245 sources), two analyses are carried out (from the screening of 179 sources), one quantitative (bibliometric) and the other qualitative (focused on five key concepts). The results show that regarding the integration of GIS with BIM and HBIM, the highest concentration of contributions is in engineering with 30.66%, followed by computer science with 21.01%. The country with the highest number of citations is China with 717, followed by Australia and the USA with 549 and 513, respectively, but relativizing the number of citations based on various indices (human development index, gross national income per capita, and population-tertiary education level), Hong Kong (18.04), Australia (10.64), and Egypt (10.16) would take the top positions, respectively. Regarding universities, the entity that has generated the most references is Delft University of Technology (the Netherlands) with 15 papers, followed by University College London (UK) with 13. Finally, the results show that GIS and BIM and HBIM provide virtual 3D models with multiple applications for buildings and infrastructures.

Keywords: building information modeling; BIM; heritage building information modeling; HBIM; geographic information system; GIS; digital twin; facility management

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1. Introduction

Today, the three-dimensional modeling of cities is becoming increasingly feasible and popular [1]. Thus, through the combination of geographic information systems (GIS) and building information modeling (BIM), the aim is to generate more controllable, collaborative, fluid, and realistic systems [2,3] with the purpose of creating a graphic platform to provide data on the landscape, the city, public services, buildings, etc. [4,5]. Likewise, in line with the smart cities philosophy, this platform can constitute the technical support for future urban operations centers and/or the creation of digital twins, facilitating the management of information in a single system [6,7].

The GIS works as a geographic database, associating all the graphic objects of the digital map that conform it through a common identifier among them. Building information modeling (BIM) is a parametric, computer-aided solution developed to revolutionize the decision-making process during the life cycle of buildings and smart cities [8,9]. It is possible to consider BIM, despite having existed for more than a decade, as a relatively recent development [10,11], which is rapidly becoming popular because it enables the three-dimensional modeling of construction projects, facilitating the linking of all types of information (architectural, structural, facilities, etc.) in a 3D parametric model [12,13]. It is, therefore, a helpful tool for all stakeholders involved in planning, designing, constructing, operating, and managing assets [14], especially when linked to the modern construction industry [15].

The variation of BIM technology when applied to historic buildings is known as heritage building information modeling (HBIM) [13,16]. The first definition of HBIM [17] appeared in 2009, by Murphy et al., 2009. HBIM is a broad term, ranging from historical data to conservation policies [18]. There are several important differences between HBIM and BIM; these arise mainly from the inherent characteristics of historic buildings, such as the uniqueness of the components and, hence, the lack of architectural families for modeling.

The interaction of GIS with BIM and HBIM offers a great capacity in data integration and quantitative analysis, providing semantically rich models, which through the synergies of these tools can have multiple applications—among others, urban planning and management [19,20], construction of buildings [21], facility management [22,23], preparing for possible emergencies [4,24], or the management of cultural heritage [25]. For example, GIS provides the HBIM model with an improved database for the management and analysis of the semantics of a heritage building, its attributes, and the relationships between the sub-elements that compose it and its environment [26]. To achieve integration among these three disciplines, it is necessary to rely on the software available in each area, considering the appropriate formats to facilitate interoperability. The choice of one or other format and interoperability procedures depends on the software used and the purpose of the work [27].

Based on a thorough review of the existing literature, the main objective of this research is to detect the most significant advances made in recent years in BIM and HBIM, including their integration with GIS. For this purpose, two analyses have been carried out: a quantitative (bibliometric) one to document the evolution of each technology based on the number of indexed scientific publications generated and a qualitative one to identify and document the most relevant progress and potential applications in terms of GIS and BIM and HBIM integration.

2. Methodology

Figure 1 illustrates the methodology used in this research. It is divided into three main stages: the search for information and selection of the most relevant contributions (Step 1); bibliometric analysis (Step 2), and the identification of a key-concept cluster and qualitative analysis (Step 3). Step 1 is developed following the guidelines of the PRISMA method (preferred reporting items for systematic reviews and meta-analyses) [28]. This is an information gathering method that follows a process structured in four phases: identification, screening, eligibility, and inclusion of the documentation. First, databases, journals, books, congresses, etc. are consulted in order to identify contributions on BIM, HBIM, and GIS and BIM and HBIM integration. These resources are classified by type and filtered by date and language, and the most relevant information is selected for analysis in the following stage. In Step 2, a quantitative analysis of the entire screened bibliography (21,149 sources) is carried out, into aspects such as where the selected contributions were published (journals, conferences, etc.), their chronological analysis, and the statistics of the contributions by subject, by country, and by entity. Step 3 consists of identifying the most relevant aspects (key-concept cluster, KCC) dealt with in the screened bibliography (21,149 sources), and studying these from the 179 references selected as a result of the application of the PRISMA method (Step 1), thus generating a qualitative analysis that develops the GIS and BIM and HBIM integration study—structured, on the one hand, in the analysis of the KCCs associated with the main technical advances in file formats, 3D model geometry and its semantics, data, and the internet of things (IoT) and, on the other, in the KCCs related to the applicability of the integrated model under the smart city concept and its corresponding particularized SWOT analysis for the eight main applications detected.

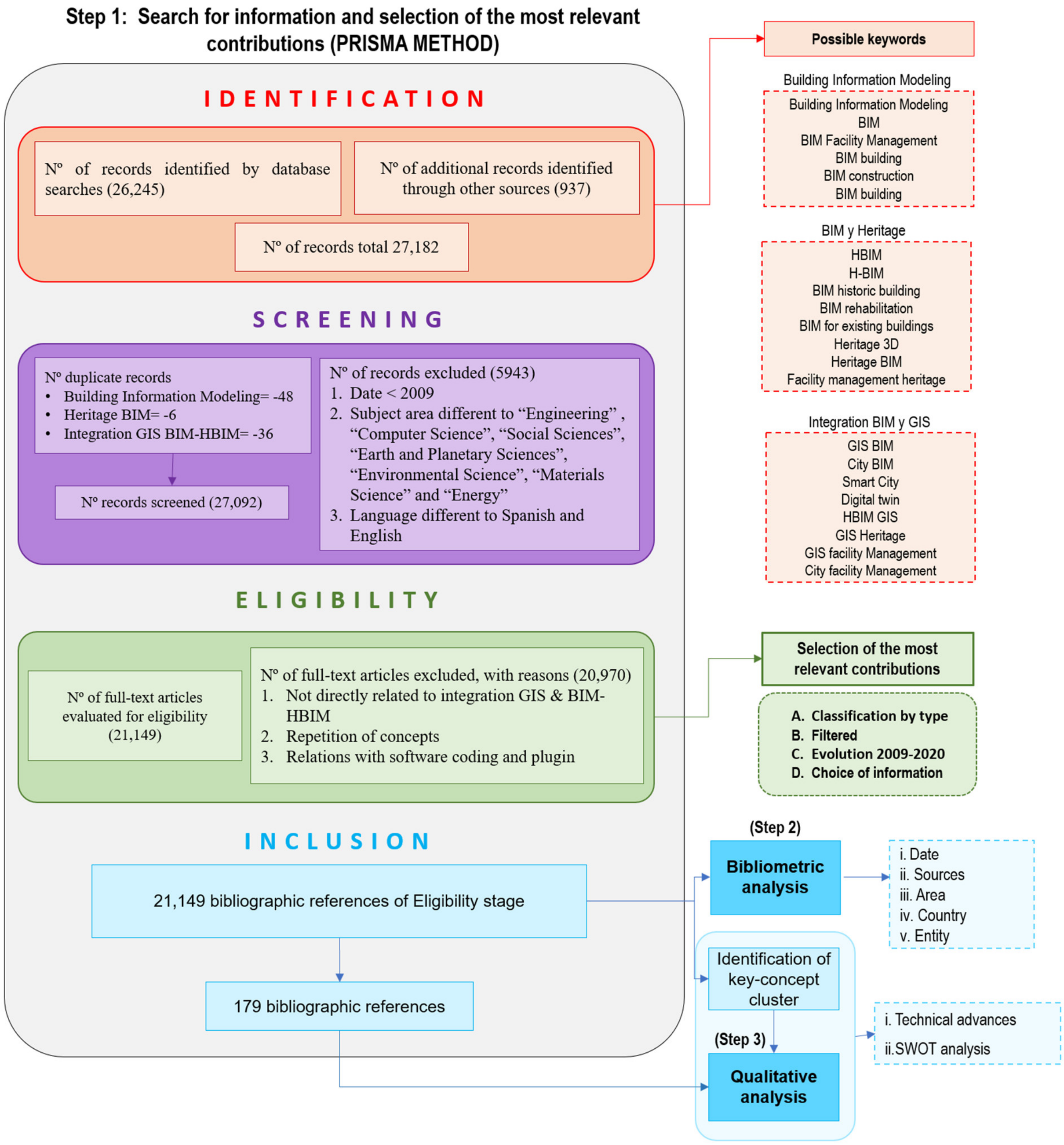

Figure 1. The flowchart of the methodology.

3. Step 1: Search for Information and Selection of the Most Relevant Contributions

3.1. Identification Stage

The search for information was focused on contributions with keywords corresponding to the themes BIM, HBIM and integration of GIS and BIM and HBIM, see Figure 1, investigating their evolution over the last few years. The reference database has been Scopus, as it has a wide coverage of the research generated in the architecture, engineering, and construction (AEC) industry compared to other databases, while offering one of the best options for interdisciplinary research topics [12] In addition, Scopus shows better performance, in terms of accuracy and coverage, compared to other search engines [29]. The initial searches associated with the identification of the Prisma method yielded integrated results of 27,182 bibliographic references; of these, 26,245 correspond to articles in magazines and conferences and 937 correspond to other sources such as books, book chapters, short surveys, notes, editorials, and letters. The search results are shown in Table 1.

Table 1. Results of the identification stage—Prisma method—of bibliographic analysis.

Theme	Document Type	
	Articles (Journals/Congresses)	Other Sources
BIM	24,826	863
HBIM	742	36
GIS & BIM & HBIM	677	38
Total	***26,245***	***937***

3.2. Screening Stage

At this stage, duplicate records are detected in the raw list of scientific contributions (27,182). The total number of duplicate records detected was 48 for building information modeling, 6 for heritage BIM, and 36 for GIS and BIM and HBIM. From this was obtained a final result of 27,092 bibliographic references (Figure 1). Those results published prior to 2009, those that do not belong to the subject areas most closely related to the research, and those written in languages other than English or Spanish were excluded from subsequent analysis.

The choice of the date of filtering from which the bibliography will be consulted, namely 2009, was due to the fact that this is when the heritage BIM concept and the integration of GIS and BIM and HBIM began to appear (Figure 2).

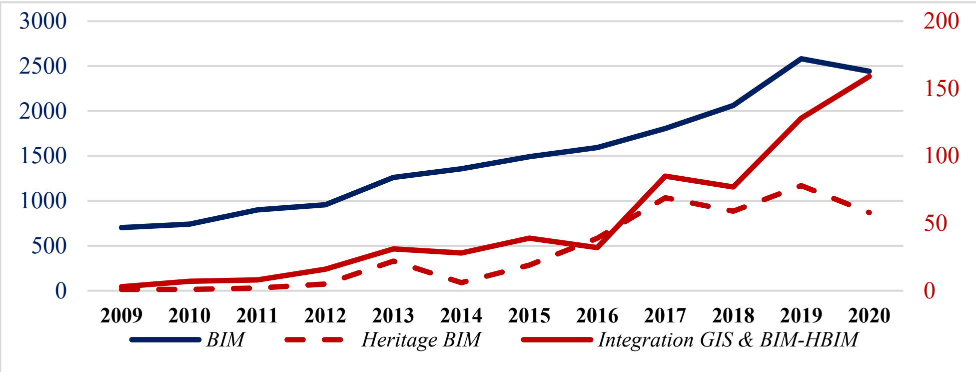

Figure 2. Evolution of scientific production indexed in Scopus after screening stage (21,149 references).

In relation to filtering by “subject area”, searches in Scopus returned results distributed in a wide range of searches. Thus, to avoid the search results being disaggregated into areas of knowledge that are not directly related to the research, those related to the AEC industry and geographical engineering were selected. The areas considered and their justifications are presented in Figure 3.

Subject area	Justification
Engineering	AEC industry professionals are the main stakeholders of GIS, BIM and HBIM.
Computer Science	Area directly related to the generation of digital models (software, interoperability and IoT).
Environmental Science	Area that relates construction / urban projects to Sustainable Development Goals (SDGs), awhich can be integrated into digital models.
Social Sciences	Use of digital models of cities with the aim of providing tools and solutions for social welfare and improving quality of life.
Earth and Planetary Sciences	GIS is directly related to this area of knowledge.
Materials Science	The GIS & BIM & HBIM integration enables the analysis of the material semantics of the 3D model and its relationship with the environment (important aspects in the life cycle of the project).
Energy	Area directly related to energy efficiency.

Figure 3. Subject areas selected from Scopus to develop the identification stage.

Therefore, considering the three filtering criteria (date of publication, subject area, and language), 5943 publications were excluded, resulting in 21,149 references subject to classification in the next phase of the Prisma method (eligibility). Of these references, 19,913 corresponded to BIM, 611 to HBIM, and 625 to the integration of GIS with BIM and HBIM. Table 2 shows these results distributed by subject area. It can be seen that the highest concentration of BIM contributions is in engineering with 34.92%, followed by computer science with 29%. As far as HBIM is concerned, computer science accounts for 29.33% of the contributions, followed by social sciences with 22.92% and engineering with 20.34%. Finally, regarding the integration of GIS with BIM and HBIM, the highest concentration of contributions is in engineering with 30.66%, followed by computer science with 21.01%.

Table 2. Percentage of references after the screening phase by thematic area.

Subject Area	BIM	HBIM	GIS & BIM & HBIM
Engineering	34.92%	20.34%	30.66%
Computer Science	29.00%	29.33%	21.01%
Environmental Science	7.66%	11.01%	12.09%
Social Sciences	8.33%	22.92%	15.95%
Earth and Planetary Sciences	8.06%	10.67%	12.44%
Materials Science	3.73%	3.93%	2.40%
Energy	4.31%	1.80%	5.49%

3.3. Eligibility Stage

In this stage, the references resulting from the screening stage are filtered again to reduce them to a reasonable number for detailed study.

Thus, those references not directly related to GIS and BIM and HBIM integration, those that were conceptually repetitive and/or focused more on software and plug-in coding than on the integration application itself, were not considered. Therefore, a total of 20,970 references were excluded, leaving 179 for the qualitative analysis. Of these publications, 16 were references related to BIM, 35 to HBIM, and 128 to GIS and BIM and HBIM integration. The reason for the considerably higher number of the latter is explained by the fact that, year after year, significant technological contributions and application cases have emerged in this area, which could be documented in the qualitative analysis.

3.4. Inclusion Stage

In this stage the references are organized into two groups (Figure 1). One group corresponds to the 21,149 publications (selected after the screening stage) used for the bibliometric study and for the identification of key-concept clusters. The other group consists of 179 publications (selected after the eligibility stage) to be studied in detail and to perform the qualitative analysis based on the key-concept clusters.

4. Step 2: Bibliometric Analysis

4.1. Analysis by Type of Source

Specifically, in BIM and HBIM, review-type references represent, on average, 5.5% of the publications in journals and 7.24% in conferences (Table 3); however, in the case of the integration of GIS and BIM and HBIM, they represent 5.8% in journals and 14% in conferences.

Table 3. Bibliographic references by document type.

	BIM			HBIM			GIS & BIM & HBIM		
	Journal	Congress	Others	Journal	Congress	Others	Journal	Congress	Others
No. contributions	9459	9688	766	215	348	48	225	372	28
% Articles	8948 (94.60%)	9118 (94.12%)		203 (94.40%)	318 (91.40%)		212 (94.20%)	320 (86.00%)	
% Review	511 (5.40%)	557 (5.88%)		12 (5.60%)	30 (8.60%)		13 (5.80%)	52 (14.00%)	

4.2. Analysis by Authors and Their Countries/Entities of Origin

Regarding authorship, the metadata of the 625 references related to GIS and BIM and HBIM integration have been analyzed, using the R package "bibliometrix" and BiblioShiny App [30]. It uses the metadata of the search results to generate a series of graphs that help us to interpret the results of the bibliometric study. Thus, it can be stated that X. Wang and J.C.O. Cheng have the highest h-index, with a value of 9. Figure 4 shows the annual production of these authors.

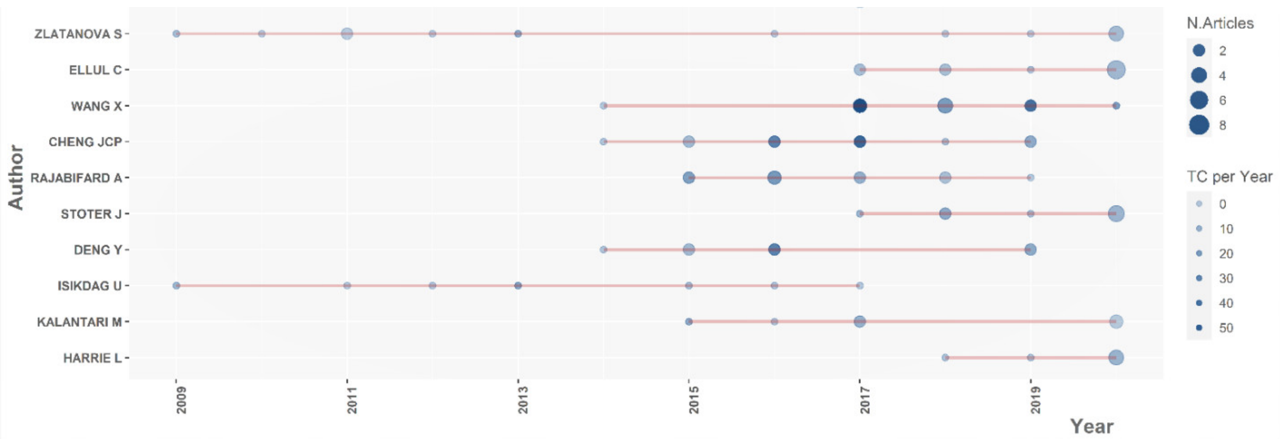

Figure 4. Top-author production over time (sorted according to total articles from 2009 to 2020).

Figure 5 illustrates the number of total citations received by country of origin from the authors of the analyzed references (bar diagram), as well as their relativization (choropleth map) with respect to the human development index (HDI) indicators [31], gross national income per capita (GNIpc, $) [32,33] and population-tertiary level of education (PTLoE) [34].

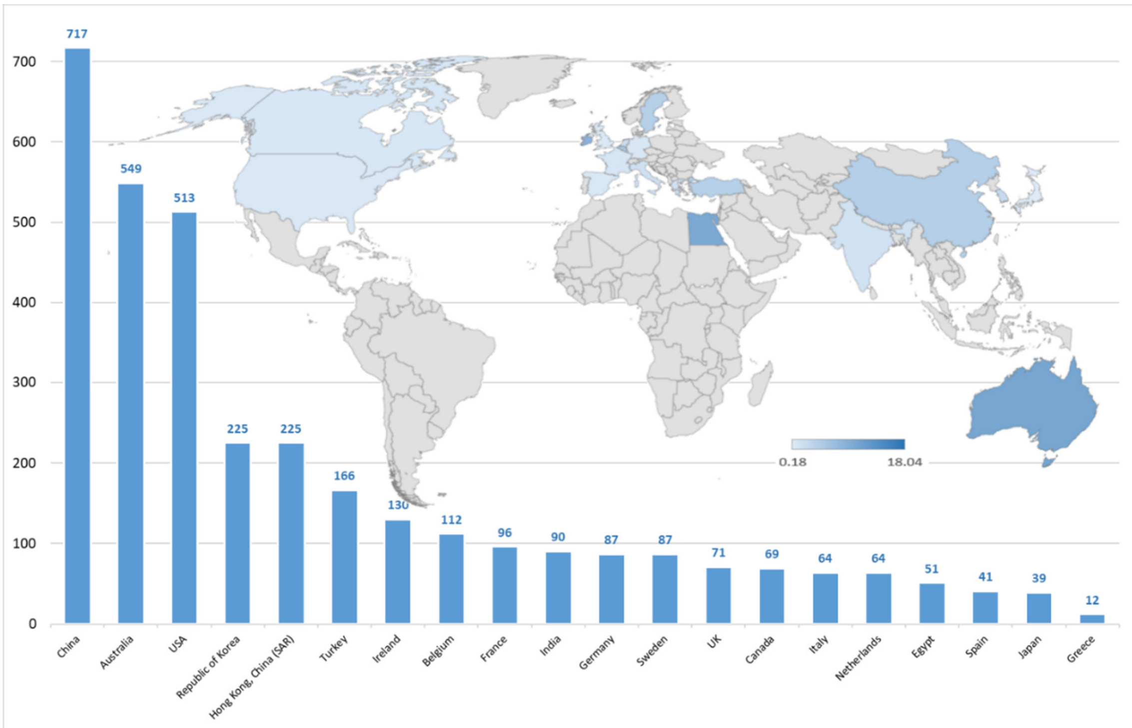

Figure 5. Number of citations by country, 2009–2020: absolute (bar diagram) and relative (choropleth map).

$$\text{Nº relative citations} = \frac{\text{Nº total citations}}{\text{HDI} \cdot \text{GNIpc} \cdot \text{PTLoE}} \cdot 10^{10} \quad (1)$$

Thus, the country that accumulates the most citations is China with 717, followed by Australia and the USA with 549 and 513, respectively, but relativizing the number of citations based on the aforementioned indices, Equation (1), Hong Kong (18.04), Australia (10.64), and Egypt (10.16) would take the top positions, respectively.

Table 4 lists the publications by countries with more than 20 contributions, and those universities that contribute the greatest number in each case. It can be seen that at the top is China with 166, followed by Italy and the UK each with 54 publications. Regarding universities, the entity that has generated the most references is Delft University of Technology (The Netherlands) with 15 papers, followed by University College London (UK) with 13.

Table 4. Publications indexed by countries with more than 14 papers (entities with most papers).

Countries with More than 15 Papers	Papers by Country	Entities with Most Papers
China	166	Chinese Ministry of Education (8) The University of Hong Kong (8)
Italy	54	Politécnico di Torino (10) Politécnico di Milano (10) Università degli Studi di Brescia (5)
UK	54	University College London (13)
Germany	48	Technical University of Munich (11) Karlsruhe Institute of Technology (7) Bauhaus-Universität Weimar (6)
United States	45	Pennsylvania State University (4) Georgia Institute of Technology (4)
Hong Kong	56	University of Hong Kong (11)

		Hong Kong University of Science and Technology (9)
Australia	22	University of Melbourne (9) Curtin University (5) Australasia Joint Research Center for Building Information Modeling (4)
Canada	22	University of Toronto (4) York University (4)
Russia	22	Moscow State University of Civil Engineering (9)
The Netherlands	21	Delft University of Technology (15) Technische Universiteit Eindhoven (4)

5. Step 3: Identification of Key-Concept Cluster and Qualitative Analysis

During the reading of the 179 selected references, the most relevant key concepts highlighted by the authors were noted. These concepts have been compared through the VOSviewer v1.6.17 software (Center for Science and Technology Studies, Leiden University, Russia) with the metadata of the 21,149 search results (eligibility stage—Prisma method). VOSviewer is a software with which bibliometric maps can be built and viewed [35]. Thus, a mind map has been configured with nodes that relate and intertwine the most relevant concepts of the publications, forming a key-concept cluster (KCC) (Figure 6). The size of the cluster node, its color, and the distance between nodes are parameters to consider in the correct interpretation of the graph. Thus, the size of the node gives information about the importance (weight) of each key concept, and the color reveals a certain grouping of the nodes by themes (similarity), while the distance advises about the interaction, so that the closer are two nodes, the greater their connection.

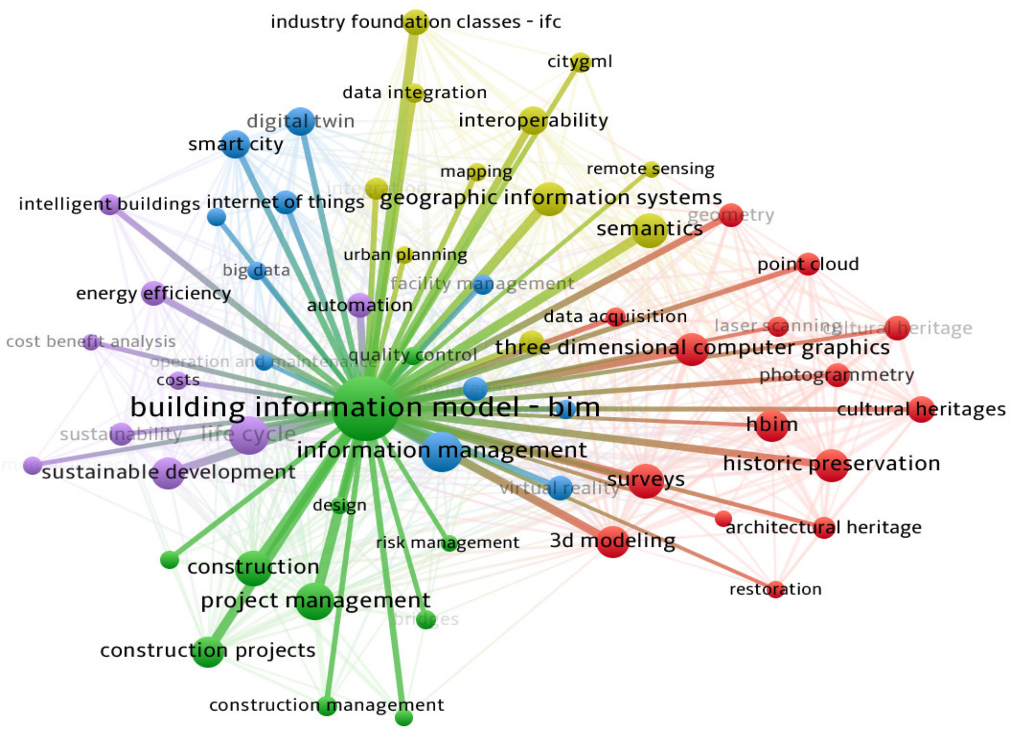

Figure 6. Integrated analysis of co-occurrence of frequent key-concepts dealing with GIS and BIM and HBIM integration 3D.

To find these results, previously, the key concepts that the software extracts from the metadata must be analyzed; in this case, there were 16,853 key concepts. To form representative clusters, an iteration frequency among the key concepts must be established in the software; this frequency will enable a mental map to be generated with clusters that contain highly disaggregated or compact nodes. After several iterations of frequency values, the optimal value was set at 41, and the software selects the 106 key concepts. After manual filtering, consisting of eliminating repeated or out-of-context terms from the research, the key concepts were reduced to 56. These key concepts are then statistically analyzed in terms of the number of repetitions ("occurrence", O) and the number of links that each key concept has ("total link strength", TLS). The results are shown in Figure 7.

Orden	*key-concept*	O	TLS	Orden	*key-concept*	O	TLS
1	*BUILDING INFORMACIÓN MODELING*	828	825	29	*Visualization*	98	98
2	*Project manager*	262	260	30	*Geometry*	91	87
3	*Construction*	227	223	31	*Integration*	78	76
4	*Construction project*	170	169	32	*CityGML*	68	67
5	*Construction management*	63	60	33	*Data integration*	57	57
6	*Bridges*	59	59	34	*Mapping*	50	48
7	*Quality of control*	55	53	35	*Urban planification*	45	42
8	*Building construction*	54	53	36	*Remote monitoring*	42	42
9	*Construction process*	48	48	37	*INFORMATION MANAGEMENT*	303	302
10	*Design*	48	47	38	*Smart city*	140	134
11	*Risk management*	42	40	39	*Digital twin*	140	122
12	*HBIM*	182	164	40	*Virtual reality*	102	99
13	*Surveys*	215	214	41	*Maintenance*	94	94
14	*Preservation of history*	192	192	42	*Internet of things*	91	89
15	*Three-dimensional graphics*	192	191	43	*Facilities management*	67	62
16	*3D model*	187	185	44	*Augmented reality*	57	55
17	*Cultural heritage*	105	101	45	*Artificial intelligence*	55	52
18	*Photogrammetry*	97	91	46	*Big data*	50	50
19	*Architectural heritage*	80	78	47	*Operation and maintenance*	49	49
20	*Point clouds*	88	86	48	*LIFE CYCLE*	187	186
21	*Laser scanner*	67	65	49	*Sustainable development*	171	170
22	*Data acquisition*	61	61	50	*Energy efficiency*	105	103
23	*Restoration*	45	46	51	*Automation*	102	99
24	*Heritage building*	42	40	52	*Sustainability*	90	90
25	*GEOGRAPHIC INFORMATION SYSTEM*	204	204	53	*Smart buildings*	71	71
26	*Semantics*	140	134	54	*Environmental impact*	55	55
27	*Interoperability*	135	129	55	*Costs*	51	50
28	*Industry Foundation Classes (IFC)*	109	109	56	*Cost benefit analysis*	43	43

Figure 7. Key-concept reduction. (O: occurrence; TLS: total link strength).

Through the VOSviewer software, the three main key-concept clusters (KCC) of the research (GIS, BIM, and HBIM) can be identified, together with their interactions (Figure 8a–c). However, additionally, it adds two more related to the most common applications of the models, namely, the life-cycle management area and the information management area (Figure 8d).

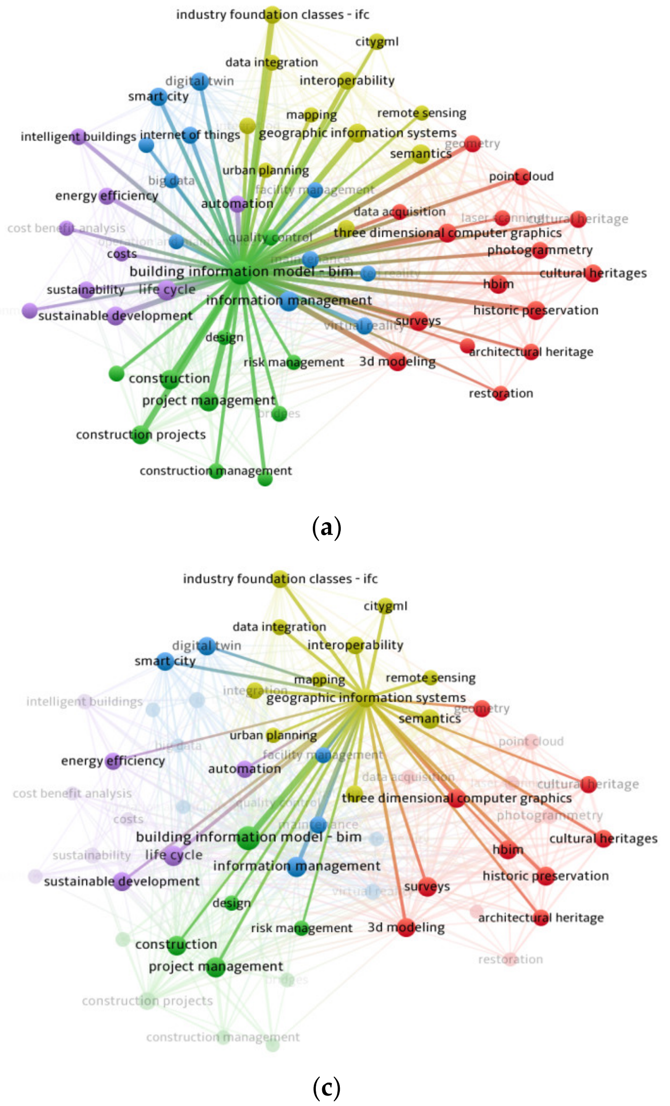

Figure 8. Key-concept cluster (KCC) determined using VOSviewer software. (**a**) BIM KCC (green); (**b**) HBIM KCC (red); (**c**) GIS KCC (yellow); (**d**) Most common applications. Life-cycle management KCC (purple) and information management KCC (blue).

When analyzing the results obtained, it should be noted that the key-concept clusters (KCC) most frequently used in the architecture, engineering, and construction (AEC) industry are:

- Building information modeling KCC. In this case, BIM is the central nucleus of integration (O: 828/TLS: 825, Figure 7), deriving within the area in other topics such as design, construction project management, and risk management (Figure 6). Likewise, it turns out to be the root for the generation of other important nodes such as, among others, information management, smart city, and digital twin, or even for the development of other KCCs themselves such as HBIM or information management, which shows the importance of BIM in the AEC industry.
- Heritage building information modeling KCC. HBIM (O: 182/TLS: 164, Figure 7) constitutes the central node of the KCC, deriving in multiple relationships both intra-area and inter-area. Within the area, strong relationships are manifested with thematic nodes such as 3D models, preservation, restoration, cultural or architectural heritage, and others related to geometry, and the data generated through surveying activities.

- Geographic information systems KCC. GIS (O: 204/TLS: 204, Figure 7) constitutes the cornerstone of this area, generating multiple relationships both intra-area and inter-area. Within the area, it is related to nodes such as semantics, visualization and file formats (IFC/CityGML), interoperability and data integration, and urban planning. On the other hand, outside its area, the interconnection network, without becoming as dense as in the case of BIM, is appreciably larger than that of HBIM. Thus, the results show that GIS is essentially linked to integration and interoperability in smart city and digital twin models, having a very close relationship with the geometry and semantics of the HBIM model, energy efficiency, automation, design, project management and construction, and risk management.

  In addition, the most common applications of the models are as follows:
- Life-cycle management KCC. Within this area there are applications oriented to sustainability and energy efficiency, cost analysis, quality control, smart buildings, and their automation.
- Information management KCC. In this regard, there are applications aimed at smart city, digital twin, internet of things (IoT), big data, virtual reality, or facility management.

6. GIS and BIM and HBIM Integration: Technical Progress and Possible Applications

Next, to facilitate the presentation, the key concepts are reorganized into two groups. A first group deals with the technical progress related to the integration of GIS and BIM and HBIM models, and a second group gathers, classifies, and scales in time a set of applications of the model under the concept of the smart city. A SWOT analysis is presented for various applications of the integration of GIS and BIM and HBIM models.

6.1. Technical Progress

The technical progress regarding the integration of GIS and BIM and HBIM models is based on 3D representation and interoperability. In what follows, aspects related to file formats, 3D model geometry and its semantics, data, and the internet of things are developed.

6.1.1. File Format

In GIS and in BIM and HBIM environments there are many formats for storing 3D geometry. Among others, the formats proposed by European Directive 2007/2/CE for the Infrastructure for Spatial Information in Europe (INSPIRE) are available [4,24], namely gbXML, Open Geospatial Consortium (OGC) [36,37], LandInfra, and IFC. Among these, the most recognized and widely used open standard in GIS is the one issued by the OGC, the "City Geography Markup Language (CityGML)"; in BIM, they are IFC formats [1].

The CityGML format is an open, standardized geometry model based on XML [4,37,38]. This format is still suitable for GIS and BIM integration because of its data interchangeability [39]. It is the most widely used international standard for storing and exchanging three-dimensional city models with semantics [23,40–42] in the geospatial domain [24]. The CityGML core module defines the basic concepts and components of the data model; therefore, it is unique and must be implemented by any system.

The IFC standard has been developed by building smart [4] as an open international standard for BIM [40]. It is a standard and interoperable format that is object oriented and capable of representing objects semantically [10]. It serves as an exchange format between different platforms, allowing BIM models to preserve all the details that are integrated in that model [1,41].

There are still many problems and technical barriers related to integration; the fundamental one is the recognition of the nature that characterizes a project when we try to link a BIM model (IFC) and a GIS model (cityGML), causing loss of information. The reality is that an IFC file, by itself, does not contain all the information of the model from which it was extracted, and, additionally, there is a difference in the nature of the BIM and GIS models; that is, a BIM model is structured with geometric figures whose representation depends directly on parameters (width, length, thickness, texture, etc.)—a quite light model; on the other hand, the GIS model is made up of meshes (junctions of points/triangulations) that, although quite flexible, have the disadvantage that a triangulation represents more than one element of the model, which makes the individualized treatment of the characteristics of an element impossible. Additionally, the file is weighty because of the amount of information that needs to be managed to generate the mesh. It is therefore necessary to continue working on an intermediate mechanism between the two types of models to achieve an integration that enables both models to interact under a nature common to both.

6.1.2. Geometry of the 3D Model and Its Semantics

In the GIS and BIM and HBIM integration, the geometry of the model is directly defined with its semantics. The semantics refers to the levels with which the 3D model is represented in the different preforms. These levels are parameters to measure the degree of semantics of the objects. They are divided into LOD (levels of detail)—more often referred to as "LoD" with lowercase "o"—for a GIS system, LOD (levels of development) for a BIM element, and LOK (levels of knowledge) in HBIM. The latter arise from the fact that authors wish to define levels of detail applicable to the management and conservation of built heritage [16].

The LoDs (from GIS) are developed in five levels of detail, from LoD0 to LoD4 (Figure 9), having different precisions and minimum dimensions, which are used to represent objects in the model of a three-dimensional city (El-Mekawy et al., 2012; Fan et al., 2011). Thus, LoD0 represents a terrain region in 2.5D; LoD1 are simple volumetric model representations, that is, "boxes"; LoD2 add the roof structure (flat or sloping) to the previous one; LoD3 present the architectural details on the exterior of the model, such as openings and wall textures; and, finally, LoD4 includes the representation of details of the interior of the model, such as the partitions and the delimitation of different spaces [41]. LoD3 and LoD4 levels containing architectural details such as balconies, windows, and rooms rarely exist because, unlike LODs (from BIM), their modeling requires multiple datasets that must be acquired with different technologies, and, often, this requires a lot of manual work [42]; hence, today, most buildings on an urban scale are represented, at best, in LoD3 [43].

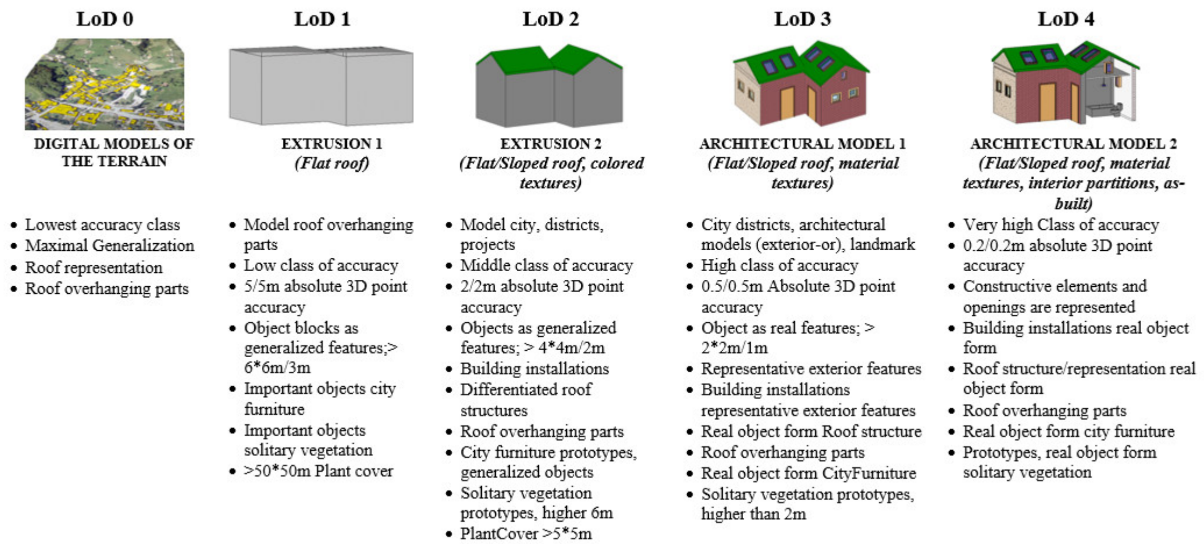

Figure 9. Qualities of levels of detail LoD/LOD CityGML (adapted from Consortium, 1994).

Inappropriately, BIM LODs are often interpreted as being associated with a level of detail rather than a level of development. As a project goes through different phases, its semantics increase at different levels of development [40] classified into five groups, from LOD100 to LOD500 [16] Popovic et al., 2017) (Figure 10). LOD100, LOD200, and LOD300 refer, respectively, to the conceptual, schematic, and detailed designs, while the LOD400 and LOD500 refer to a level of development associated with the complex documentation of the project, reaching the final character of an as-built [40].

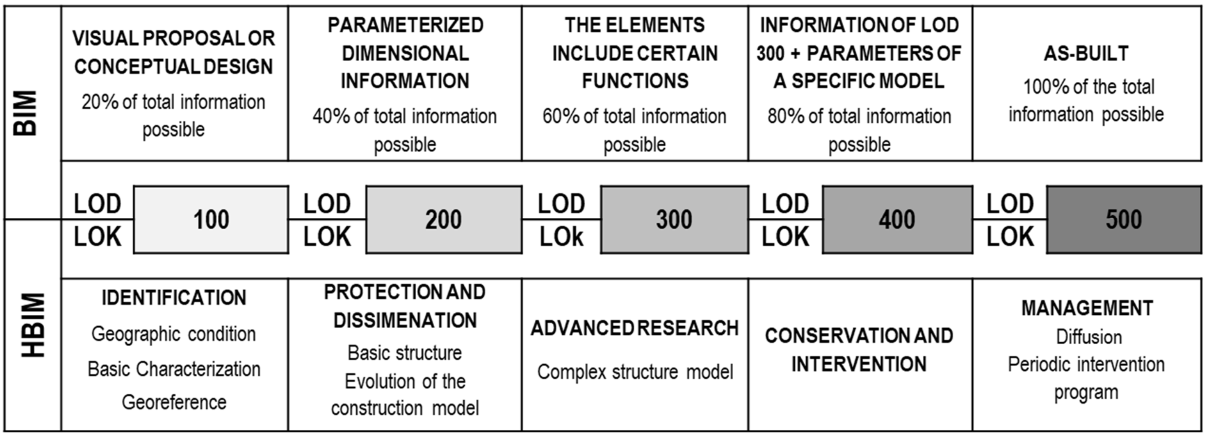

Figure 10. Knowledge levels (LOK)—HBIM and levels of development (LOD)—BIM.

LOK knowledge levels represent the semantics of heritage management [16], classifying from LOK100 to LOK500 (Figure 8). LOK100 is associated with the identification of the heritage asset and its basic characterization; LOK200 enables the graphic characterization and sufficient information for the development of actions related to the legal protection of the asset and its strategic planning; LOK300 provides greater detail about the characterization of graphic entities to the point of being able to show the results of specialized investigations carried out using archaeological methodology or other specific disciplinary follow-up and diagnosis studies; LOK400 includes specific conservation and intervention actions on the asset's elements; and finally LOK500 deals with efficient management of HBIM models.

6.1.3. Data Generated by Surveying Activities

The collaboration between various stakeholders involved in a project consists of sharing data through interaction, communication, exchange, and coordination [9]. Feeding a model with existing data enables not only better visualization but also coordination between views and efficient construction management with considerable cost reduction, whether in the construction, rehabilitation, operation, or maintenance phase.

Today, the most widespread dimensions of a BIM model range from 3D to 7D. 3D represents the three-dimensional model of the project, 4D includes the information about its time sequence [44], 5D refers to the costs of the model elements, 6D contains information on sustainability, and, finally, 7D includes aspects of the management programs in the operation and maintenance phase [16].

As for the HBIM models, and with the objective of coordinating all existing information, another five dimensions are usually adopted, coinciding in name with those referred to for BIM models, 3D–7D, but with somewhat different concepts. Thus, the 3D HBIM model, in addition to being related to the three-dimensional model, considers the data collection performed on the building. 4D is related to historical evolution. 5D cannot be directly related to the actual construction costs as in BIM, since, obviously, the building is already constructed; therefore, the transfer of this dimension from BIM to HBIM is not direct, and a parallelism is usually established with the estimated cost of the associated intervention process [16]. 6D includes the cultural context, and, finally, 7D addresses preventive programs and conservation of the building. Figure 11 illustrates the relationship between the BIM and HBIM dimensions.

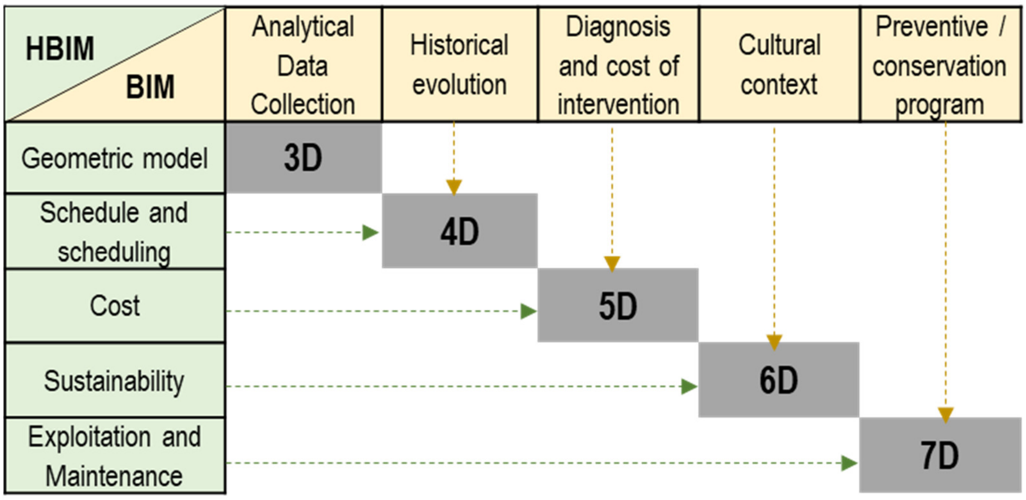

Figure 11. Dimensions BIM vs. HBIM.

6.1.4. Applicability of the Model under the Concept of Smart City

Smart city has been a well-adopted concept in urban development worldwide [45–47], being, by analogy, the "motherboard" where smart buildings should be inserted, generating a new public–private relationship [39]. It encompasses different definitions, but all of them share, as a basic pillar, the use of technology [27], constituting a facilitating element in the improvement of public services, sustainability, and efficiency [9]. Smart city 3D [37,48], part of the digital twin concept, which was introduced in 2003 within a manufacturing concept and life-cycle management [44,49]. Digital twins integrate IoT, machine learning, artificial intelligence, and big data analysis to create digital simulation and feedback models, which interact with their physical counterparts, updating themselves [50]. Figure 12 lists several application cases and technologies developed in the field of digital twins of cities, extracted from the bibliographic consultation carried out.

Year	*Model*	*Application*	*Country*	*Ref.*
2021	GIS & BIM	Digital Twin of the Docklands area, Dublin	Ireland	[51]
2021	GIS	Cambridge, citywide 3D Model	USA	[52]
2020	GIS & BIM	Integrated GIS-BIM platform to represent and visualize 3D cadastral data	Greece	[41]
2020	HBIM	BIM Legacy	Spain	[18]
2020	GIS & BIM	Construction project documentation using GIS-BIM integration	Iraq	[2]
2020	GIS & BIM	Automated valuation methods using the cost approach in a GIS-BIM integration for smart city valuations	Italy	[27]
2019	GIS & BIM	Digital twin of Helsinki	Finland	[53]
2019	GIS & BIM	Design and implementation of a digital campus system based on GIS-BIM integration	China	[21]
2018	BIM	Virtual Singapore	Singapore	[54]
2017	BIM	UK National Digital Twin	UK	[55]
2016	HBIM	Petro BIM	Spain	[56]
2015	HBIM	GIS 3D-BIM integration for documentation and restoration of historical monument, Jeddah	Saudí Arabia	[25]
2015	BIM & FM	BIM & Facilities Management in a large university complex	UK	[57]
2015	GIS & BIM	GIS-BIM integration for district modeling	Italy	[5]
2013	GIS & BIM	Generating Lod (0-2) Citygml models in greater municipality of Istanbul	Turkey	[40]
2012	GIS & BIM	A unified building model for 3D urban GIS	Sweden	[4]
2012	GIS & HBIM	GIS-HBIM integration to register and manage cultural heritage sites	Ireland	[10]
2012	BIM	Platform design for efficient GIS-BIM interoperability	Korea	[3]
2008	GIS-BIM-CAD	GIS-BIM-CAD integration by service-based virtual 3D city models	Germany	[48]

Figure 12. Some examples and application cases of digital twins extracted from the bibliography [2–5,10,18,21,25,27,40,41,48,51–57].

7. SWOT Analysis

In summary, a digital model can be given a number of applications that correspond to the model of reality. To identify the main aspects that could affect the application of GIS and BIM and HBIM integration in the above possible uses organized according to their relationships with the key-concepts of application of the model of the co-occurrence analysis qualitative results (*heritage conservation, cost and quality control, construction project, life-cycle analysis, facilities management, sustainability and energy efficiency, interoperability and semantics,* and *urban and transport planning*) a SWOT analysis is proposed (Figure 13). The result of this SWOT analysis is shown in Table 5.

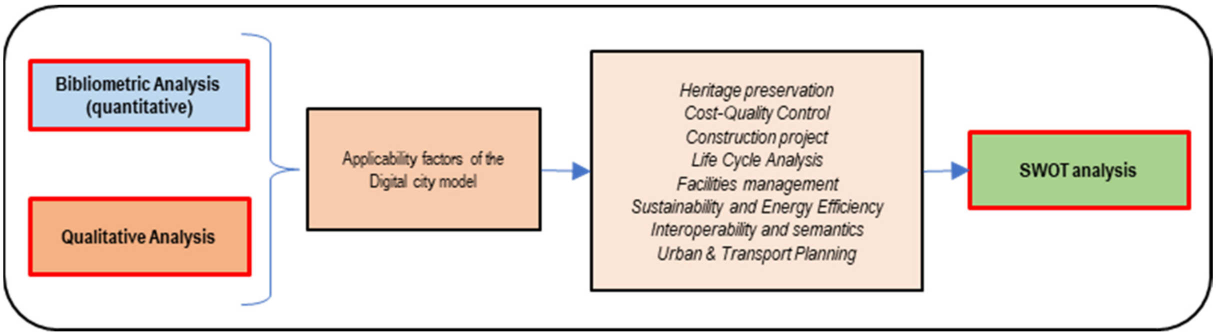

Figure 13. Data source for SWOT analysis.

Table 5. SWOT analysis of GIS and BIM and HBIM integration.

Strengths			
Heritage conservation	**Cost and quality control**	**Construction project**	**Life cycle analysis**
Manage semantic knowledge information	Reduce costs [43]	Synchronize design and planning [29]	Evaluate model changes over time [13]
Be able to contain geometric or semantic information [26,40]	Improving product quality and optimizing management [51]	Simulate the environment surrounding the project and its reactions [57]	Plan the maintenance and renewal of assets
Modeling quantitative and qualitative information [29]	Managing risk and safety [58–63]	Manage all project information	Simplify and reduce the time to obtain and update information
Integrate and digitally manage heritage	Improve productivity [64,65]	Enable the process to be more dynamic and efficient [13]	Analyze decision making [7]
Automating performance evaluation and heritage conservation	Save time	Plan the project according to its local environment, and not only at the level of the uniqueness of a building	Analyze buildings throughout their life cycle, considering the surrounding environment [63]
Optimize the dissemination of heritage		Planning decision making [64]	Virtual building management [62]
Improving risk management		Manage construction [60]	Facilitate monitoring processes
Facilities management	**Sustainability and energy efficiency**	**Interoperability and semantics**	**Urban and transport planning**
Predicting maintenance through simulation [26,52]	Integrally improving urban sustainability [20]	Automate the production of 3D digital documentation	Facilitating the improvement of public services
Optimize, through HBIM, the management and maintenance of historic buildings	Planning and managing the sustainability of cities [66,67]	Sharing and exchange of information between BIM and geospatial objects [68]	Improved 3D visualization and use of virtual reality (VR) and augmented reality (AR) [6,29]

Organize in a 3D environment the information generated throughout the design and construction process [69]	Reducing the time required for environmental impact assessment of projects [70–72]	Enabling extended communication between stakeholders to manage a common data environment	Create digital simulation models that are updated based on their physical counterparts [73]
Managing public spaces [74,75]	Designing smart neighborhoods in an ecological and efficient way [76–80]	Sharing of information, knowledge and communications among all stakeholders [9]	Enabling simulation of urban phenomena or designs based on a real city
Infrastructure maintenance [75]	Perform urban microclimate analysis [76]	Integrating IoT	Integrating machine learning and artificial intelligence
Monitoring systems through 3D simulation	Reducing construction and demolition waste (CDW) [77]	Accessing and updating information	Enable exploration and analysis of the management tasks in a city [41]
Inventorying large-scale equipment	Designing community energy systems [81–84]	Predicting trends	Smart city management and human trafficking within them
Calculate demand and large-scale production	Forecast energy costs of the building/city	Visualize and compare on a large scale the project and finishes of your materials	Simulation of natural disasters and intelligent response systems in urban disasters [81,82,85]
	Weaknesses		
Heritage conservation	**Cost and quality control**	**Construction project**	**Life-cycle analysis**
Uncertainty when dealing with historical buildings	Specialized professional training of employees is required	High cost of implementation of GIS/BIM technology in company [84]	Require a well-fed model
Uniqueness of the components of the heritage asset	3D model management is an arduous and continuous task over time	Difficulty to supply the model with the information generated during the construction process	Unfeasibility of many projects due to IoT requirements
Limited historical, semantic and graphic information	Customers are reluctant to pay the high cost of managing the model	Require very powerful hardware for integrated project modeling	Failure to upgrade CMMS (computerized maintenance management system/software) systems to 3D formats
Absence of life cycle information	Lack of clarity in the legal framework for BIM technology	Lack of free licenses for model integration	Lack of financial resources on the part of the public administration to generate and manage these models

High cost of data capture	High maintenance cost of an integrated quality management system	Lack of information management orientation of the model	High cost of updating the BIM model throughout the life cycle [43]
Facilities management	**Sustainability and energy efficiency**	**Interoperability and semantics**	**Urban and transport planning**
Requirement to manage and use complex and disparate data [43]	Lack of semantic information for the creation and management of the energy model	Limitation in representing the semantics of the models in different platforms	Insufficient sensor technology to create a smart city
Lack or insufficiency of information for Facility Management	Models very far from reality	Incompatibility between models	Lack or absence of quality LIDAR data available in public administrations
Losing information between construction and operation phases	Restriction of access to user energy consumption information	Requirement for constant software upgrades by stakeholders	Extremely high cost of data acquisition to generate the model
BIM software is not designed to perform Facility Management	Few urban-scale 3D models are at the LoD4 as-built level of development	Poor stakeholder training in interoperability and coding concepts	Preference of the public administration to finance 2D GIS models, due to their lower cost, in relation to 3D GIS
Difficulty in data transmission for bidirectional integration with management software	Low level of development of energy efficiency software at the macro-urban level	Lack of all BIM model information in the IFC models	High number of working hours in the elaboration of an adequate city model
Incompatibility between models	Lack of sensor technology for the management of as-built models	There is no universal platform [84]	Errors in the actual representation of the model [84]
Opportunities			
Heritage conservation	**Cost and quality control**	**Construction project**	**Life-cycle analysis**
Take the opportunity to virtualize the management/visit heritage assets through digital models as a consequence of certain risks (for example, pandemics)	Globally widespread standardization to facilitate collaboration and data integration [11]	The availability of BIM methods and routes for the implementation of digitization of buildings and structures [14]	The growing interest in passing management CMMS 2D to 3D
High number of historic buildings in need of intervention [18]	Optimization in 3D visualization of production cycle control	The existing need for information exchange and cooperative work at a global development level [13]	The need for access to asset information through a 3D virtual library

The need for easy access to historical and heritage information	The use of simulation as a tool for reducing maintenance costs	The need for effective building management	Constant development of monitoring technology
The extensive development in virtual and augmented reality for representing heritage	The need to remotely manage and supervise the production process	The requirement to optimize design time	The requirement of public entities in transparent and collaborative management
Overall interest in managing and preserving historic buildings		Need to optimize the bidding process for the project	The growing need for remote asset management
Facilities management	**Sustainability and energy efficiency**	**Interoperability and semantics**	**Urban and transport planning**
The need to optimize digital asset management	The need for an integrated element to facilitate sustainability and efficiency improvements	Requirements to improve risk sharing among stakeholders [86]	The possibility of 3D representation in disaster management
The need to optimize the Computerized Maintenance Management Systems/Software (CMMS)	The availability of solar incidence simulation tools at city scale	The need of stakeholders to increase the capacity to face rapid technological change in the AEC sector [87]	The development of new technologies and the use of the smartphones for the interrelation of the user and the city
Improved accessibility of high-capacity Internet services	Global requirements to promote energy control and resource savings	The existing need to improve trust among stakeholders [86]	The creation of regulations to motivate the use of BIM models in structures and public buildings
Potential development of applicable sensorics	The need for tools for global and comparative 3D statistical control of energy expenditure	The wide range of software and plug-ins	GIS and BIM and HBIM will be increasingly in demand in urban planning/regeneration
Threats			
Heritage conservation	**Cost and quality control**	**Construction project**	**Life-cycle analysis**
Reliance on laser scanning for the capture of certain data	Few professionals with training and accreditation in BIM supervision	Unwillingness of contractors, clients and users to employ digital BIM modeling [84]	High cost of implementation of a BIM system for life cycle management
Loss of historical information due to inadequate management	Increased project cost, due to quality control with BIM	Lack of customers requesting the digital 3D service because of its price	Non-availability of historical information on structures and their maintenance

Lack of interest in disseminating heritage	Difficult accessibility and expensive 3D quality control equipment.	The resources required are expensive	High cost of sensor technology required for monitoring during operation/intervention phase
Need for significant investments [86]	Lack of idiosyncrasy to promote monitoring and control of the project with 3D models	Lack of regulatory requirements for the development of private projects in BIM	Requirement for highly qualified human resources for remote monitoring of assets
Facilities management	**Sustainability and energy efficiency**	**Interoperability and semantics**	**Urban and transport planning**
Lack of resources for 3D modeling of installations	Lack of initiative on the part of technicians to switch to the use of 3D software for energy calculations	High cost of software	Lack of initiative on the part of public administrations to transform their 2D GIS to 3D.
3D models are usually architectural.	Deficiency in the characterization of materials in historic buildings	High cost of software [87]	Representation in LoD 3 and LoD 4 still very expensive
The high cost of software licenses CMMS	The reduced practice of sustainable design in many countries	Lack of standardization [86]	Lack of requirements from authorities to submit regeneration/urban planning proposals in GIS and BIM and HBIM
Incompatibility of 2D and 3D model connection formats		Difficult relationship between stakeholders	Stakeholder limitations in programming language training

8. Conclusions

Nowadays, 3D representation and virtual management are a necessity in the architecture, civil engineering, and construction (AEC) industry. Modern practices require that projects be developed and managed collaboratively, digitization being the link that unites stakeholders in real time. This global collaborative work seeks to relate the local BIM/HBIM project with its environment, to manage and experiment, via simulation, with all the variables and reactions that condition that project—that is, integrated management including not only the factors that affect the BIM/HBIM project but all the assets that surround it on the site, hence the need to unify environment (GIS) and project (BIM/HBIM).

This research has compiled the significant advances made in recent years in BIM/HBIM and its integration with GIS. Two types of analysis have been carried out, one quantitative to document the evolution of technology based on the number of scientific publications indexed in this field and the other qualitative to compile the main advances and relevant factors of the GIS and BIM and HBIM integration. As a result, it can be concluded that no models have been found that can be considered fully optimal in the aforementioned integration, which is due to the fact that they propose different geometric modeling approaches, different semantics, and very different catalogs of entities considered. However, it should not be forgotten that there are different approaches that have been highlighted to disciplines/methodologies/approaches, in which BIM/HBIM manages the information with a clear orientation toward design, construction, costs, materials, facilities, etc.—in short, the life cycle of built assets—while GIS 3D is proposed as a geosystem that seeks global visualization and analysis, and that, for this purpose, requires all existing entities to be considered in the context of digital twins, from built assets to the natural environments in which they are located; terrain, natural resources, plots, urban planning, service networks, etc.—that is, the context that buildings, nature, and the human environment share. Therefore, perhaps the integration between both information universes should not seek full and total conversion between systems but rather a link between both models, fully managing the entities themselves and accessing lightweight external digital models.

However, in GIS and BIM and HBIM integration, the benefits outweigh the difficulties. For example, the greatest virtue is being able to contain geometric or semantic information in a 3D format as a virtual library. This information is accessible to stakeholders, allowing greater interaction. The evaluation of project performance can be automated, as well as its dissemination on a global scale. This integration achieves cost reductions both in the design and service stages, since the environment surrounding the project (including possible natural disasters) and the reactions it undergoes can be simulated, thus improving productivity, the analysis and prevention of negative impacts on the design, and its economic return.

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Abbreviations

AEC	Architecture Engineering and Construction
BIM	Building Information Modeling
CityGML	City Geography Markup Language
GIS	Geographic Information System
GNIpc	Gross National Income per capital
HBIM	Heritage Building Information Modeling
HDI	Human Development Index
IFC	Industry Foundation Classes
KCC	key-Concept Cluster
LOD	Levels of Detail//Levels of Development
LOK	Levels of Knowledge
OGC	Open Geospatial Consortium
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
PTLoE	Population-Tertiary Level of Education
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TLS	Total Link Strength
XML	eXtensible Markup Language

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