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Review

BIM Visual Programming Tools Applications in Infrastructure Projects: A State-of-the-Art Review

Jorge Collao [1], Fidel Lozano-Galant [2], José Antonio Lozano-Galant [2] and Jose Turmo [1,*]

[1] Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya Barcelona TECH, 08034 Barcelona, Spain; jorge.collao@upc.edu
[2] Department of Civil Engineering, Universidad of Castilla-La Mancha, 13003 Ciudad Real, Spain; fidel.lozanogalant@uclm.es (F.L.-G.); JoseAntonio.Lozano@uclm.es (J.A.L.-G.)
* Correspondence: jose.turmo@upc.edu

Featured Application: This study aims to review the state of the art of visual programming algorithm applications in BIM infrastructure projects.

Abstract: The Building Information Modeling (BIM) methodology improves architectural and infrastructure projects by digitizing their processes throughout their life cycle stages, such as design, construction, management, monitoring, and operation. In recent years, the automation of these processes has been favored by the use of visual programming (VP) tools that have replaced conventional programming languages for visual schemes. The use of these tools in architectural projects is becoming increasing popular. However, this is not the case in infrastructure projects, for which the use of VP algorithms remains scarce. The aim of this work is to encourage both scholars and engineers to implement VP tools in infrastructure projects. For this purpose, this work reviews, for the first time in the literature, the state-of-the-art and future research trends of VP tools in infrastructure projects.

Keywords: Building Information Modeling (BIM); infrastructure projects; visual programming; dynamo; grasshopper; python

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1. Introduction

The Architecture, Engineering, and Construction and Operation (AECO) projects industry is characterized by its dynamic and evolutionary nature [1,2]. This dynamic spirit has been reflected mainly by the technological developments made by the AECO industry [3,4], which has undergone a revolution in the traditional manner of developing projects [5,6]. This technological growth is mainly focused on the following three trends: (1) Constructive element prefabrication [7–9]—the physical components of construction projects are assembled in specialized workshops and then delivered to construction sites for their placement. (2) Projects' carbon footprint reduction [10–12]—AECO projects have significantly contributed to the current climate crisis due to the environmental impact of their construction stages [13]. Therefore, the aim of regulation is to reduce the emissions of the projects undertaken by this industry. [14,15]. (3) Project digitalization [16–18]—this trend simulates different scenarios during the project life cycle to optimize the resources from early stages [19], and is considered the most important trend in the AECO industry from an information technology perspective [20].

Currently, project digitalization is strongly connected with the development of the Building Information Modeling (BIM) methodology [21]. BIM refers to a collaborative environment that generates information models of all stages of a projects' life cycle [22,23]. A number of scholars (see, e.g., [24–37]) have discussed the benefits of implementing this approach in different AECO projects. However, these works are mainly focused on building projects [38,39]. Analyses of the benefits of BIM for infrastructure projects (such as bridges, tunnels, and roads) are relatively scarce in the literature. This difference is particularly highlighted in works that have studied these benefits for the digitalization of infrastructure projects [40,41]. This gap is explained by infrastructure projects' characteristics, such as their unique geometry and high design requirements [42]. Due to these unique characteristics, the implementation of the BIM methodology is more difficult.

Computer programming has contributed by developing different BIM applications, which are used to digitize projects in the AECO industry [43]. However, these applications have only covered the main BIM applications [44], such as (1) modeling, (2) generation of documentation, and (3) visualization. Other BIM applications, such as (1) parametric design, (2) generation of analysis graphs, and (3) emission estimation, have not yet been encompassed. To address this gap, the AECO industry initially developed specific line code programming applications [45], which were incorporated into BIM software. These programming applications generate algorithms that define different process sequences by defining command lines of instructions [46]. However, the work interface and the high programming skills required by these applications are both challenging for AECO industry professionals [47]. To resolve these issues, BIM software development companies have generated VP tools.

These tools generate algorithms based on visual expressions for creating process sequence scripts [48]. Hence, these algorithms are represented as process charts rather than the code lines of conventional programming. The most common VP tools in the AECO project industry are the following:

(1) Dynamo; This VP tool is associated with Autodesk Revit software and is the most commonly used by the AECO project industry [49]. A number of scholars have used this VP tool; for example, Valinejadshoubi et al. [50] developed an algorithm to record data from a set of facilities to BIM models. This platform was used to record real-time data of facilities of a residential building in the city of Ottawa (Canada). Santoni et al. [51] applied an algorithm that optimizes the visualization of BIM model elements in a heritage project in the city of León (Spain).

(2) Grasshopper: This is a plug-in developed by Robert McNeel & Associates for the Rhinoceros 3D modeling software [52,53]. Among the scholars that have used this VP tool, the following can be highlighted. Abbasi et al. [54] developed a parametric simulation platform to study the energetic performance in projects. The proposed platform was used to measure the energy relationships in an industrial assembly project in Shiraz (Iran). Freitas et al. [55] proposed an algorithm for estimating solar energy capture for photovoltaic projects in the city of Brasilia (Brazil). Massafra et al. [56] studied the behavior of wooden structures of various heritage projects in Bologna (Italy) through 3D surface scanning. Then, the scanned data was connected to BIM models using interoperable VP scripts.

(3) Python; It is a programming language developed by Van Rossum [57]. Initially, this language was as open source. Then, it was integrated with the BIM environment via the development of application programming interfaces (APIs). APIs are applications that create algorithms that allow the communication of two or more software packages [58]. Authors working with APIs include Kensek (2018) [59], who developed a VP educational module for BIM energy development projects. This module was applied in architecture courses in the city of Los Angeles (US). Martinez et al. [60] proposed an automated control algorithm to inspect modular units on industrial assembly projects. This algorithm was used in various residential projects in Canada. Andriamamonjy et al. [61] created an automated deployment of an air treatment system for construction sites using an integrated platform between building performance simulation (BPS) and BIM models. Then, this platform was implemented in several facilities' management projects in Belgium.

All VP tools are composed of the following elements [58]: (1) Input; initial information required by the VP algorithms to develop the information flows. (2) Nodes; these elements are operators that generate the algorithm's information flows by subjecting the input data to specific functions. (3) Output; Final information delivered by the nodes during the execution of the algorithm. (4) Connectors; these digital lines join the different nodes to generate the algorithms.

Figure 1 presents the basic structure of the VP nodes of the state-of-the-art tools reviewed in this paper. Figure 1a presents an algorithm developed using the Dynamo tool. This algorithm represents a simple mathematical multiplication operation [62]. In this case, the inputs representing the numerical factors required to execute this operation are associated with this type of element, the nodes are the multiplication operation of the present example, and the output corresponds with the results of the mathematical operation. Figure 1b presents a script made using Grasshopper tool. This visual script describes the generation of parametric vector planes within a spatial interface [63]. In this case, the input corresponds with the range of values that each axis can adopt to build the plane of the vector, the nodes define the construction of a vector plane as the central operation of the algorithm, and the outputs provide the coordinates and specific variables of the parametric plane. Finally, Figure 1c presents a VP algorithm developed using the Python tool. This application shows how to record the time [64]. The input data is represented by a stopwatch that records the real time at each instant, the nodes correspond with functions that the algorithm requires to extract and separately represent the different measurements of the chronometer (hour, minute, second), and the outputs are a list of the different variables extracted by the nodes to be associated with other elements of the BIM model. In each of these figures, the inputs are represented in red, the nodes in blue, and the outputs in green.

The work of Korus et al. [65] was selected as a motivating case to illustrate the methodology and benefits of applying VP algorithms. The aim of this study was to improve the conventional process of designing arch bridges. This process is based on an iterative optimization combining structural and geometrical design, which has a large component of manual labor. To link the BIM model with the structural model (Finite Element Method, FEM) of the bridge, a VP algorithm was created in Dynamo. To illustrate the flow of information followed by this study, a fragment of the developed algorithm is presented in Figure 2. This figure is divided into the following elements: (1) Inputs; These elements represent the information required to generate parameterized structural bars, such as geometric vectors defining the longitudinal geometry of each structural member, structural properties (area and moments of inertia), and physical properties (Young's module, Poisson ratio, and the specific weight of the steel bars). (2) Nodes; These elements connect the information extracted from the input and process it to optimize the cross- section and geometry of the bridge elements. This optimization is carried out by an iterative process that analyses the geometrical response of the structure for a set of given loading cases. (3) Outputs; These elements include the results of the optimization process (geometry and cross-section of the bridge elements) in the BIM model.

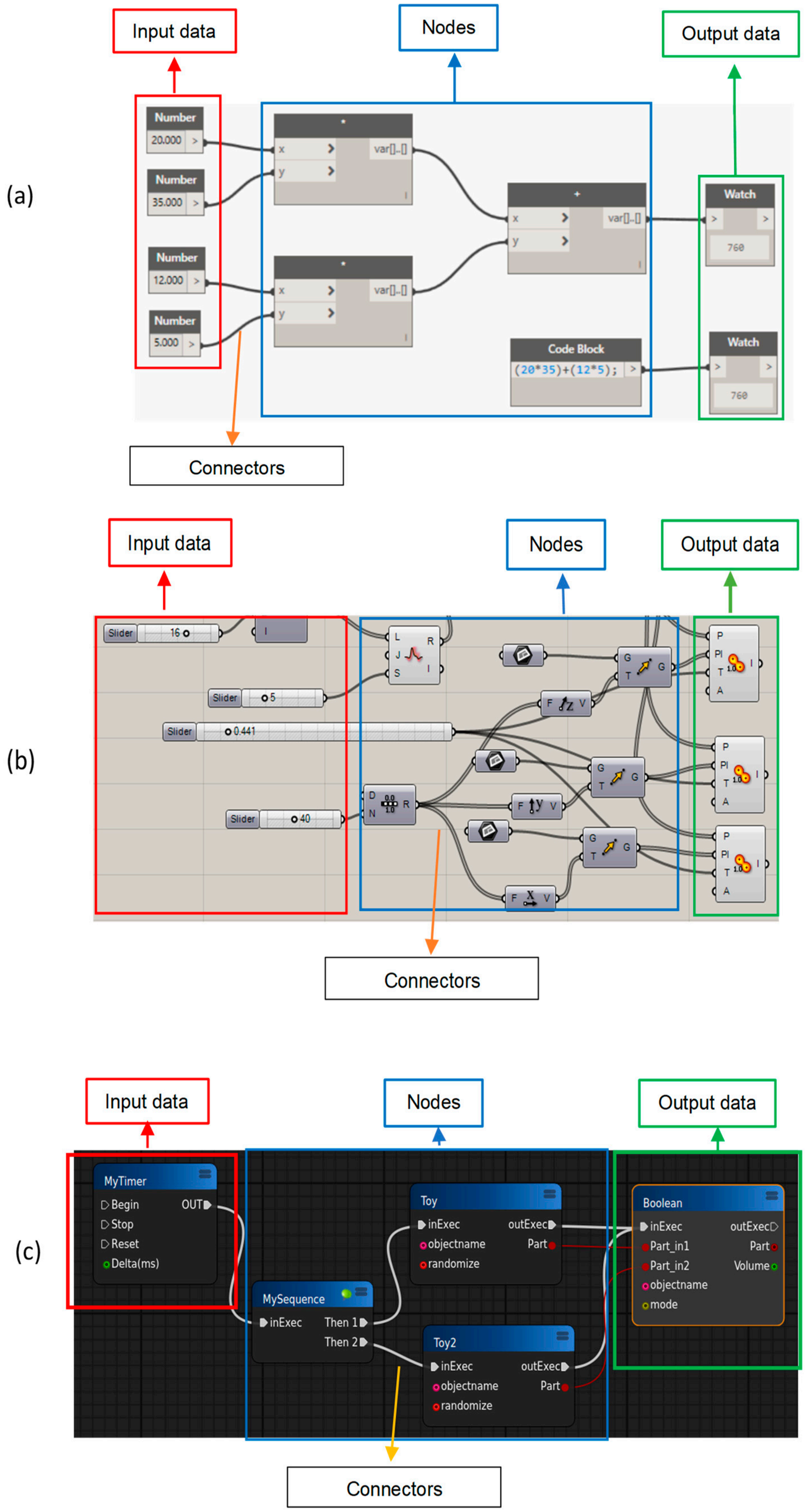


Figure 1. Basic structure of VP scripts. (**a**) VP script of the Dynamo tool, (**b**) VP algorithm of the Grasshopper tool, and (**c**) VP script of the Python language tool.

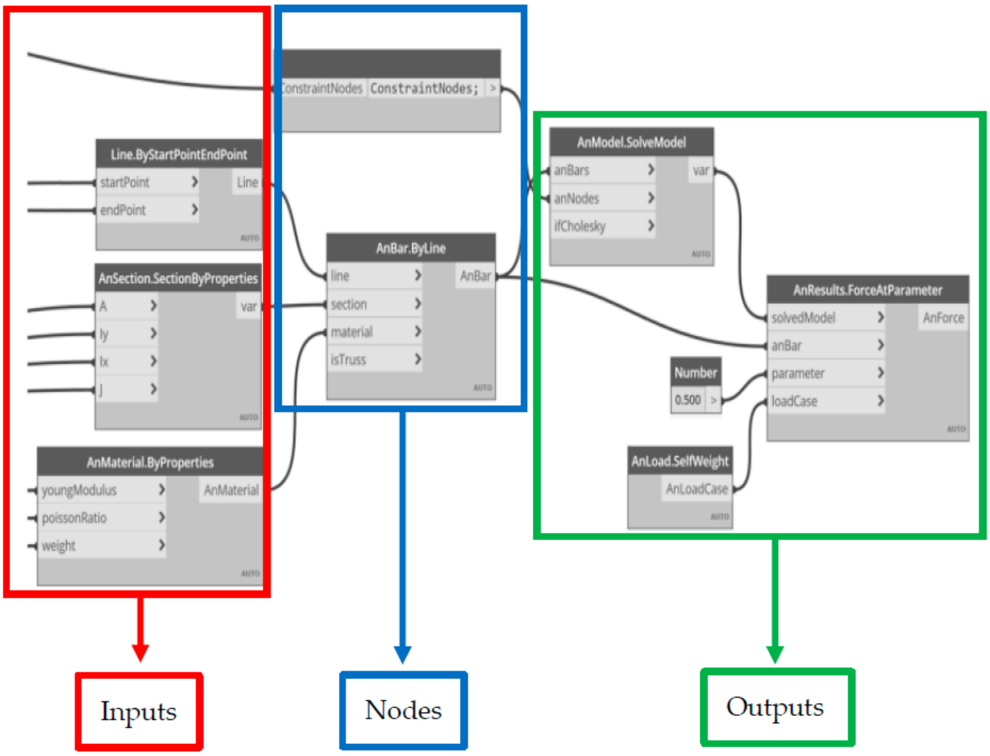


Figure 2. Fragment of the VP algorithm developed by Korus et al. [65].

The application of this VP algorithm was validated based on the S3 high-speed road project located in the central-western region of Poland.

The VP algorithms are executed automatically due to the direct communication between their nodes [66]. This automation has created essential advantages in the digitalization of AECO projects through BIM methodology because different BIM software can communicate through these VP algorithms. In the literature, the following benefits of VP algorithms can be highlighted:

(1) Friendly interface [66]; This technological tool offers an interactive interface for AECO professionals without advanced knowledge in programming. This advantage has been studied by Saito et al. [67], who compared both visual and line-of-text (conventional) programming languages for beginning students. The methodology proposed in this study used programming operations in video games of basic mathematical operations and logic processes to study students' responses. This study showed that VP offered a more intuitive interface for beginning students due to the positive impact that visual schemas had on programming learning.

(2) Reducing modeling time [68]; VP tools can create parametric figures through different scripts to associate model design information with automatic geometry generation processes, thus reducing modeling time. This benefit was illustrated by Kensek [69], who studied the interoperability of BIM model information flows in solar façade projects by comparing the following two methodologies: (1) Using VP algorithms; These scripts were used as a bridge to allow the transfer of information between BIM and energy models, which were developed independently. (2) Using Industry Foundation Class (IFC) files; These data packages are the most popular interoperability format in the BIM environment. These files were used to update both BIM and energy models through IFC native files. Both methodologies were applied in building projects in California (US), showing that visual algorithms were more efficient in transferring information between BIM and energetic models.

(3) Automation of repetitive processes [70]; Such as naming project drawings with a specific nomenclature. This advantage was illustrated by Nezalmaldin [71], who

studied the automation provided by the VP algorithms of the Dynamo tool in the conversion of CAD drawings to BIM models. For this purpose, he compared his results with those of the conventional CAD-BIM manual conversion methodology. This benefit was validated using different buildings in the city of Stockholm (Sweden).

(4) Providing connectivity with non-BIM software [72]; VP tools provide a bridge between a variety of software types (such as Microsoft Excel and Access) and BIM models. This advantage is illustrated in Boeykens et al. [73], who evaluated the interoperability between CAD and BIM models in architectural projects. In this study, a Python algorithm was developed to connect the information of the BIM model with Excel spreadsheets, extracting the information of urban surfaces and spaces. This evaluation was applied to a digital reconstruction project of a synagogue in the city of Vienna (Austria).

The advantages of the VP tools in the automation of the AECO industry may be implemented in various project types due to the versatility of their applications. However, reality indicates that the AECO industry has favored using these tools in architecture projects rather than infrastructure projects [73]. This is due to the following reasons: (1) Lack of standardization [74]; Infrastructure projects have unique typologies that are difficult to model with parametric design. (2) Complexity of projects [75]; The life cycle of these projects requires information models with a high degree of technical data. Therefore, the interoperability of these projects is challenging. (3) Delayed BIM implementation [76]; The BIM methodology has focused on the architecture sector because most countries have focused their implementation plans on this type of project.

The visual algorithms developed by the main VP tools in the literature are interpretative, because each function within the script is associated with a visual object. Therefore, the execution of the algorithm requires the recognition of the visual object associated with the script and the execution of the algorithm process sequence. This operational duality increases the computational time with respect to traditional non-VP codes. Due to this limitation, it is more challenging for these tools to execute the reading of visual objects and the processes in parallel. Another common limitation of the VP algorithms relates to their slower interoperability with the web operators due to the preference of Web developers to work with traditional coding. Connecting VP scripts with Web operators requires disassembling the visual algorithm into different lines of text. This characteristic reduces its practicability. At present, it remains a challenge to develop Web design tools that can efficiently connect with VP algorithms.

In summary, two gaps were detected. Firstly, the automation of infrastructure projects through VP algorithms is not as frequent as in building projects. Secondly, the relationship between VP tools and infrastructure projects has not been reviewed in the literature. To fill these gaps, the aims of this study were to undertake a literature review of the use of VP algorithms in infrastructure projects to show the trending research, encourage scholars and engineers to use these tools, and present new potential applications for VP tools in infrastructure projects. Therefore, the scientific contribution of this work is to present the state of the art of the current applications of VP tools in infrastructure projects, in addition to its future research trends.

The aim of this paper is to present the first literature review of the use of VP tools in infrastructure projects to show the trending research and motivate the use of new potential applications. The applied search methodology consists of a series of filters associated with specific keywords. Each filter allows the analysis of different scenarios, both the study of the state-of-the-art applications and the trends.

This paper is organized as follows: Section 2 describes the literature search methodology applied in this study. Section 3 presents the results and analysis of the literature research. Finally, this bibliographic review's conclusions are presented in Section 4, together with a description of the future research trends identified.

2. Materials and Methods

In this section, the methodology, keywords, and filters that were applied in the bibliographic review are presented. This study used the system presented by Navarro et al. [77], who applied this search methodology in the review of the state-of-the-art decision-making techniques in sustainable bridge design, and which has been applied extensively since then [78–80]. This review system was selected due to its organized manner of searching the literature. Figure 3 presents the flowchart that describes the literature search methodology. This figure is divided into the following three search filters: (1) Keywords—defines the words that describe the methods, techniques, tools, and project types necessary to establish the review scope. (2) Category—the disciplines or specific areas of knowledge in which the search is defined; for instance, architecture, engineering, and construction. (3) Language of the papers.

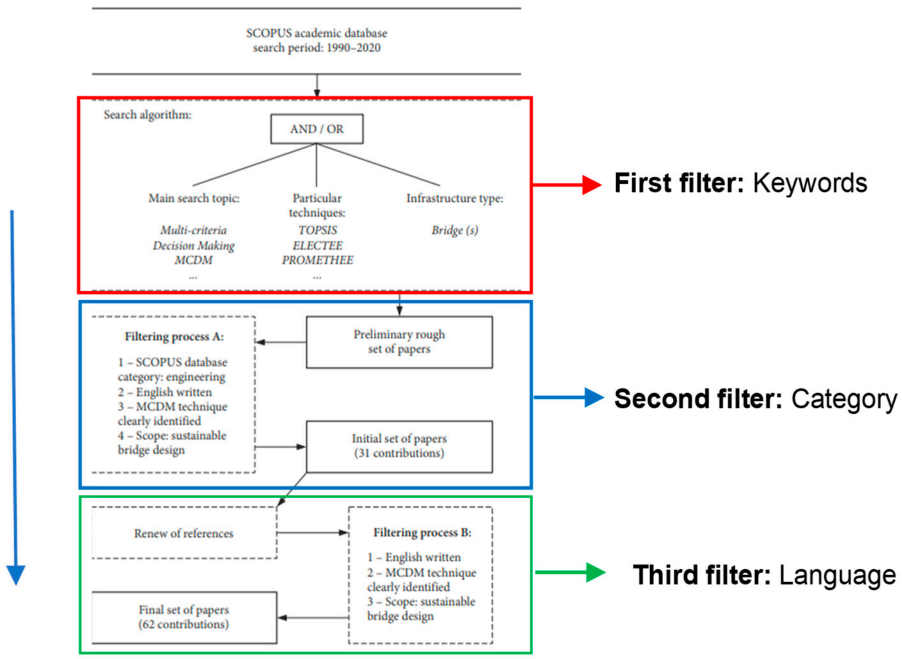


Figure 3. Flowchart of the literature review methodology presented by Navarro et al. [77].

This bibliographic search considered the following databases: (1) Web of science [81], to search academic papers, and (2) Derwent Innovations Index [82], to review patents. Table 1 represents the keywords, filters, and other conditions that were used to generate this review. The figure is divided into three rectangles. Each rectangle represents each filter of Figure 2. The bibliographic search filters were: (1) Keywords—this filter was the most extensive in terms of content. Therefore, the keywords were classified into the following groups: (1.1) Project type; bridges(s), roads(s), highways(s), tunnels(s), architectural project(s) and infrastructure(s). (1.2) BIM concepts; BIM, building information modeling (US), building information modelling (UK), building information model(s), bridge information modeling, and tunnel information modeling (1.3) VP tools; VP, Dynamo, Grasshopper, and Python. Boolean generators of the OR type connected the words of each group. In contrast, Boolean generators of the AND type connected each filter group. (2) Category—the disciplines selected for this review were engineering, instrumentation, computer science, construction building technology, transportation, and automation control systems. (3) Language—this review only considered works in English.

Table 1. Keywords and filters considered in this bibliographic review.

First Filter			Second Filter	Third Filter
1.1 Project type	1.2 BIM Concepts	1.3 VP tools	2. Category	3. Language
Bridge(s)	BIM	VP	Engineering	Only works in English
Road(s)	Building information modeling	Dynamo	Instrumentation	
Highway(s)	Building information modelling	Grasshopper	Computer science	
Tunnel(s)	Building information model(s)	Python	Construction building technology	
Architecture	Bridge information modeling		Transportation	
Architectural	Bridge information model(s)		Automation Control	
Infrastructure(s)	Tunnel information modeling			
Building(s)	Tunnel information model(s)			
	Road information modeling			
	Road information model(s)			

In the next section, the results of the bibliographic search of Table 1 are presented and analyzed. The analysis included both a bibliographic review analysis and a topic breakdown of the found studies.

3. Results and Discussion

This section presents the results of the literature review methodology in Section 2. Section 3.1 presents a general quantitative analysis of the results. Section 3.2 presents an analysis that mainly considers the topics studied and the VP tools used by the reviewed studies.

3.1. General Results Analysis

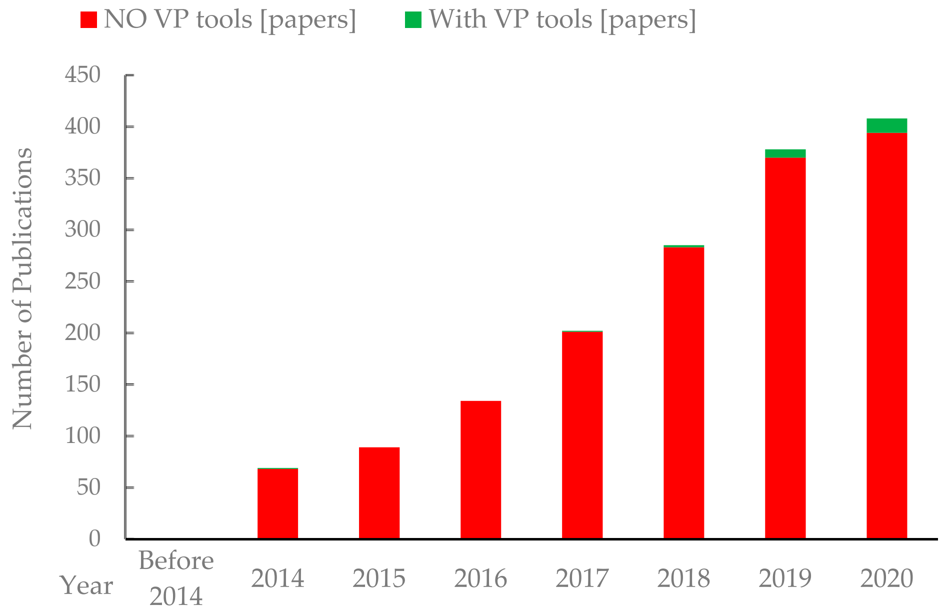
This section presents and analyzes the following scenarios: (1) general search results, (2) results by document type, (3) contributions' geographical distribution, and (4) institution types that supported the reviewed publications.

In general terms, this bibliographic review found a total of 153 studies. Of these, 127 studies were associated with architecture and buildings projects (83%) and 26 with infrastructure projects (17%). Both types of projects presented their first contribution in 2014.

Figure 4 presents the temporal distribution of the studies reviewed in the following scenarios: (1) Figure 4a represents the papers' distribution between architecture projects (red bars) and infrastructure (green bars) projects. (2) Figure 4b shows the distribution between the number of studies that applied VP tools in BIM infrastructure projects (green bars) and those that applied BIM in infrastructure projects without VP tools (red bars). IN addition, this figure incorporates a column called the percentage ratio that indicates the relationship between the number of papers of infrastructure projects and architectural projects. The X and Y axes of the figures represent the number of papers and the year, respectively. (3) Figure 4c presents the distribution of publications found for each keyword in Table 1.

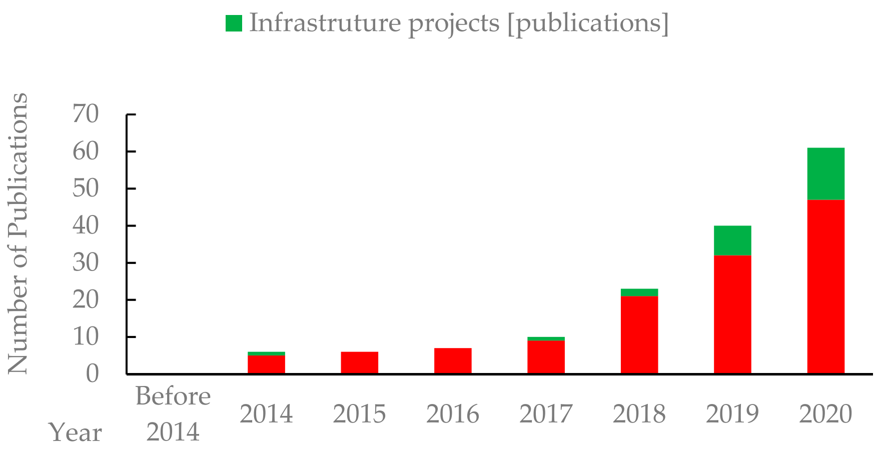
Figure 4a shows that from 2014 to 2018, the number of papers that applied VP tools in architecture and buildings projects was higher than that in infrastructure projects. However, this trend was considerably reduced in 2019 and reversed in 2020. This change indicates that the interest in the research of VP tool applications in civil engineering projects is growing. Therefore, these applications offer an essential research focus for the future.

(**a**)



Year	Before 2014	2014	2015	2016	2017	2018	2019	2020
With VP tools [papers]	0	1	0	0	1	2	8	14
NO VP tools [papers]	0	68	89	134	201	283	370	394
Percentage ratio [%]	0	0.01%	0%	0%	0.00%	0.01%	0.02%	0.04%

(**b**)



Year	Before 2014	2014	2015	2016	2017	2018	2019	2020
Infrastruture projects [publications]	0	1	0	0	1	2	8	14
Architecture and buildings projects [publications]	0	5	6	7	9	21	32	47

Figure 4. *Cont.*

(c)

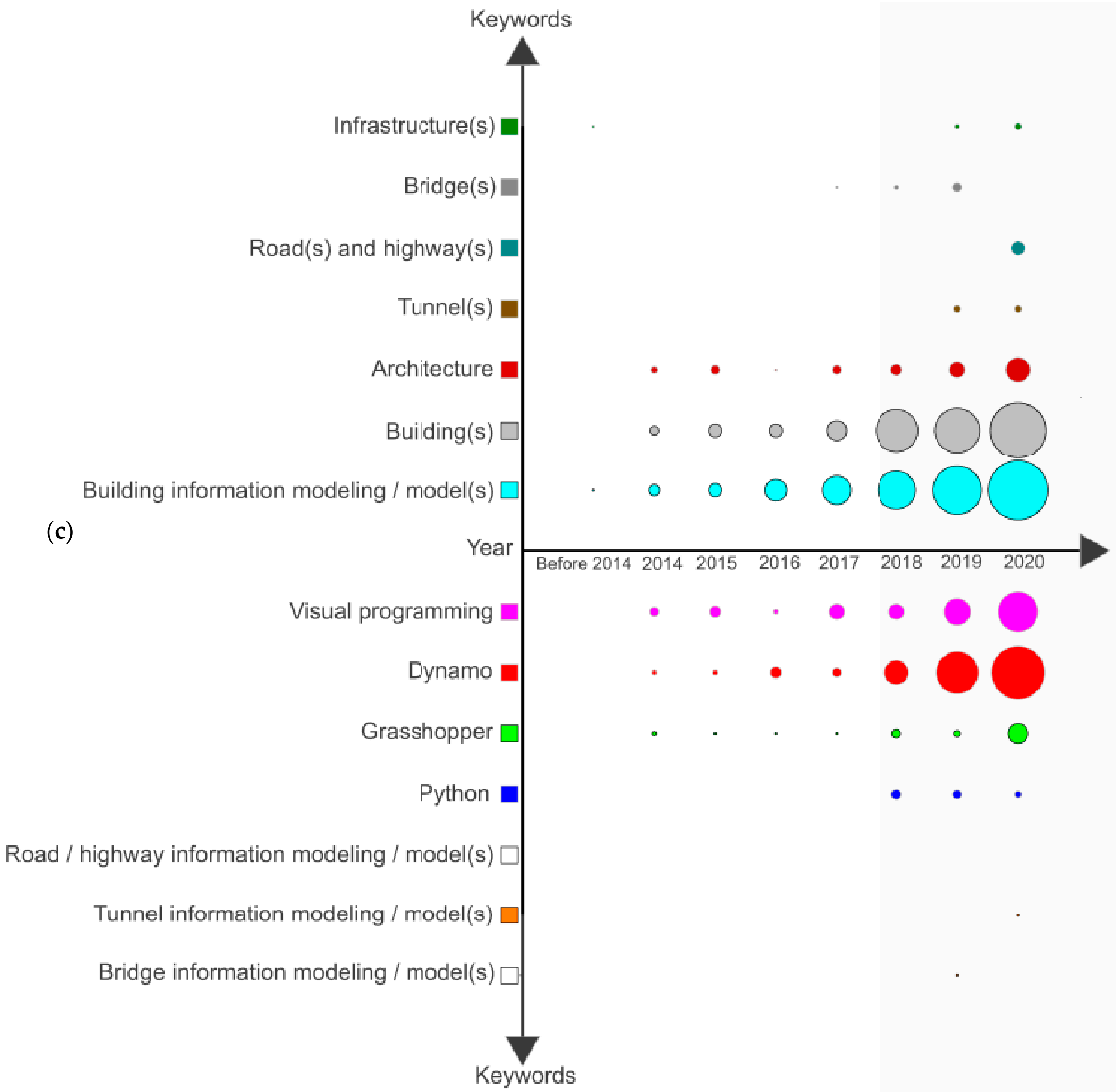


Figure 4. Comparative scenarios of the reviewed publications. (**a**) Comparison between the groups of papers associated with architecture and infrastructure projects, (**b**) comparison between papers' groups of the VP applications and No VP applications in infrastructure projects, and (**c**) distribution of publications found by associated keywords.

The data in Figure 4b show that the interest in applying BIM methodology in infrastructure projects is growing. This trend is consistent, as indicated by the literature review studies of BIM applications for civil engineering projects [83–89]. In addition, this growth is also observed in Figure 4a. However, during the 2018–2020 period, the growth rate of VP tool applications in infrastructure was higher than that presented in Figure 4b, which only registers a growth peak of 3.55% in 2020; that is, although the research interest in these tools has steadied concerning architecture projects, these applications still have a reduced presence in the field of BIM infrastructure projects. This is explained because the main BIM applications in the civil engineering sector are already standardized by default in the leading BIM software [90,91]. Therefore, they do not require automation by VP tools. However, overcoming these limitations has been the main reason for the growing interest in the application of VP tools in civil engineering projects.

Figure 4c shows that the keywords of buildings, building information modeling/models, VP, and Dynamo are associated with most of the keywords in Table 1. These words also show that the specific research towards the development or study of algorithms of VP in BIM projects is growing, as presented in Figure 4.

Table 2 presents the classifications by the document type of the infrastructure projects reviewed in this study. These types are patents, papers, reviews, and conferences. The table columns are document type, the number of papers by document type, and the percentage values for each document type relative to the total number of reviewed papers.

Table 2. Distribution of reviewed articles by document type.

Document Type	Number of Works	Percentage [%]
Patent	13	50.00%
Paper	9	34.61%
Meeting	3	11.54%
Review	1	3.85%
Total works	26	

Table 2 shows that 50% of the reviewed works are patents. These are focused on protecting the property of created algorithms. Some examples of these patents are: (1) Shi et al. [92], who developed an integrated platform in Dynamo that parameterizes geometries of roads and bridges. The invention was focused on the design, quantification, and control of public projects. (2) Wu et al. [93], who generated a Dynamo algorithm to create parametric models for tunnels. This invention integrated data from specialized geological software into BIM models. (3) Ma et al. [94,95], who developed a parametric model in Dynamo to generate beams for bridges. This platform integrated the topographic data, design processes, and assembly of construction elements. Academic papers contributed 33.33% of the reviewed contributions. Among these studies are: (1) O'Shea et al. [96], who developed a sensor integration method using VP scripts to assess existing projects' structural health. This platform was implemented in road infrastructure projects in the city of Dublin (Ireland). (2) Biancardo et al. [97], who created a parametric model to generate the roadway of highway projects. Then, they evaluated its interoperability with Civil3D and Rhinoceros software to study the loss of information. The platform was used in a road project in Italy, evaluating different design alternatives. (3) Khan et al. [98], who evaluated the safety conditions in excavation works using an automated environment of VP algorithms. The platform was used in an example project of Autodesk Revit software. In the case of meetings, the following studies are highlighted: (1) Qin et al. [99], who integrated a network of sensors to inspect bridges using algorithms created in Python. This network allowed the interoperability of databases to be cleaned based on sensors. (2) Karóczkai (2018) [100], who developed parametric models in Grasshopper for BIM models from ArchiCad software. (3) Briscoe et al. [101], who studied the applications of parametric models in Dynamo to manage green habitats. This study applied VP tools to study BIM infrastructure projects' sustainability. However, it was undertaken using a non-energy approach. The study developed by Haubler et al. [102] is of particular interest because it is the only review study found in the search. Therefore, it is the only effort to review the applications of VP tools in infrastructure projects. This study reviewed the VP checking tool applications in railway design projects in Germany.

Table 3 presents the distribution by geographic region of the principal authors' works. This table includes the following columns: countries, the number of publications per country, and the percentage that each country contributed to this bibliographic review. Countries that each contributed only one study to this review are grouped in a cell called "Other countries". These countries are Germany, Hungary, Ireland, Italy, Poland, Slovenia, South Korea, Taiwan, and Turkey. As a visual complement, Figure 5 represents the geographical distribution map of the publications.

Table 3. Geographical distribution of reviewed publications—Web of Science database [81].

Country	Number of Publications	Percentage (%)
China	13	50.00%
United States	3	11.54%
England	2	7.69%
Other countries	8	30.77%

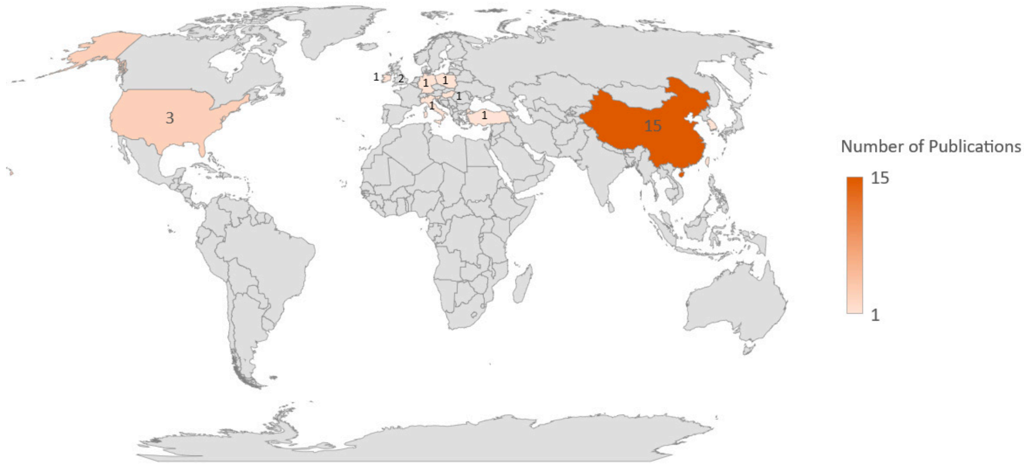


Figure 5. Geographical distribution map of publications.

Table 3 shows China is the country making the greatest contribution to the revised publications (50%) and has generated all the reviewed patents. This is explained as follows: (1) BIM implementation [103]—Civil engineering projects are priority development objectives in the national BIM implementation plan. (2) Investment in infrastructure development [104]—The high economic growth that the country has experienced in the past 15 years is due in part to the high investment in the development of infrastructure. This investment has enormously strengthened the AECO industry and the technological development of the BIM environment. The cases of the United States and England, which represent 17.24% of the publications reviewed, show a decisive difference with China. The lower presence of these English-speaking countries in this bibliographic review can be explained as follows. The United States' case is explained mainly by the following two reasons: (1) Absence of a federal BIM implementation law [105]; Which reduces the development of a VP tool standard for the infrastructure sector. (2) The private sector has focused its BIM implementation on building projects [106]; This reason also explains the case of England, which has not been able to achieve its BIM implementation plan's objectives [107].

The category of other countries in Table 3 presents the following results: (1) Continental Europe: seven countries developed studies (Germany, Hungary, Ireland, Italy, Poland, Slovenia, and Turkey). Therefore, this group of countries contributed 24.14% of the reviewed publications, and is the geographic region with the second-highest number of reviewed publications. (2) South Korea: This country contributed one study to the review.

Table 4 presents the institutions that supported the reviewed publications. This table includes institution type (higher education institutions, public entities, or companies), institution name, and associated country.

Table 4. Classification of reviewed publications according to associated supporting institution.

Institution Type	Institution Name	Country	Reference
Higher education institutions	Technical University of Munich	Germany	[102]
	Mardin Article University	Turkey	[108]
	University College Cork	Ireland	[96]
	University of Naples Federico II Federico	Italy	[97]
	University of Portsmouth	England	[109]
	Chung Ang University	South Korea	[98]
	University of Texas Austin	United States	[101]
	Hohai University	China	[110]
	Southeast University	China	[111]
	Tongji University	China	[99]
	Beijing University of Civil Engineering & Architecture	China	[112]
	Fuzhou University	China	[113]
	Changzhou Planning and Design Institute	China	[114]
	Zhejiang University	China	[115]
Public entities	Henan provincial communications planning	China	[93]
	Beijing municipal road and bridge-building	China	[116]
Companies	Shangai baoye group corporation Ltd.	China	[117]
	Kumming atide software Ltd.	China	[118]
	China communications Shangai sanhang TE	China	[119]
	Shanghai pudong road and bridge bituminous Ltd.	China	[92]
	SGIDI engineering consulting group Ltd.	China	[120]
	Sichuan wenchuan maerkang highway LLC	China	[121]
	Chengdu engineering management Ltd.	China	
	Sichuan gaolu construction consulting Ltd.	China	
	Sinohydro Bureau 11 Zhenzhou Ltd.	China	[122]
	CCCC first highway engineering Ltd.	China	[94]
	China railway engineering group 4 Ltd.	China	[123]
	China tiesiju civil engineering group 5 Ltd.	China	
	Graphisoft SE	Hungary	[100]
	Sambo Engineering Ltd.	South Korea	[124]

The data in Table 4 show that the contributions made by institution type of the reviewed publications are higher education institutions with 48.28% (14 publications), public entities with 6.89% (2 papers), and companies 44.83% (13 publications). These results show the academic–public sector has led the research effort of VP tool applications in infrastructure projects (55.17%). This difference between public–private agents is explained because both academia (mainly) and governments have led the BIM implementation in their AECO industries [125]. However, when the higher education institutions and companies' contribution percentages are compared, it is possible to observe a slight difference. In addition, 87% of the reviewed patents (13 works) have been registered by companies. This indicates that the private sector is considering the benefits of the infrastructure projects' automation through VP tools. This trend is essential to increase the VP tool applications because the presence of the private sector is most significant within the AECO project industry [126].

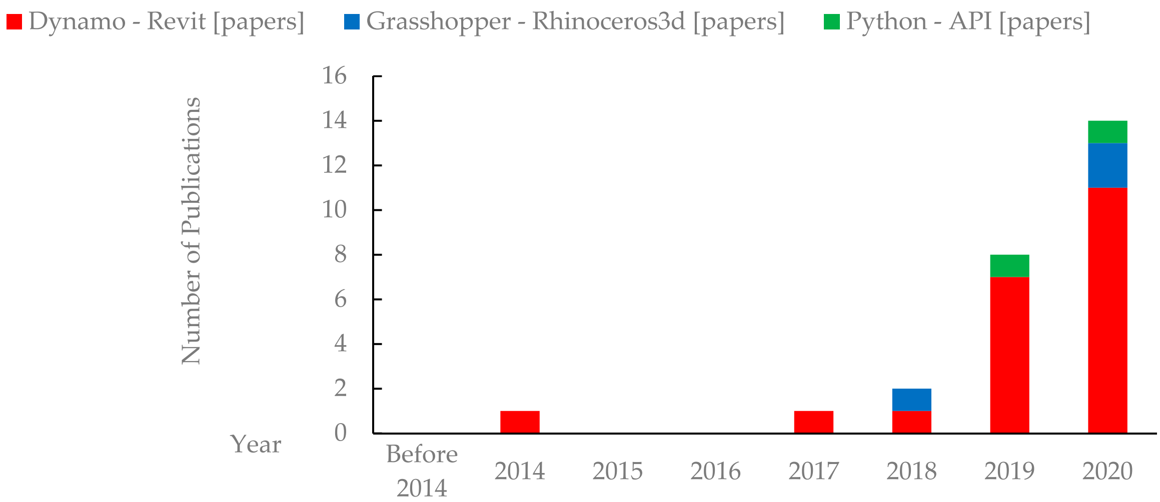
Table 4 indicates that no specific institutions lead the VP tool research in infrastructure because the institutions have each contributed one study. This decentralized distribution of the research is due to the fact that VP algorithms are focused on the projects' specific needs [127] and not on the application of VP tools throughout the life cycle of infrastructure projects.

Table 4 also shows that China has developed 50% of the academic sector publications, 100% of the public sector publications, and 85.71% of the reviewed patents. By comparison, Europe, the US, and Asia (not China) have contributed 50% of the academic studies. This reflects the fact that China is firmly leading the transition in VP applications' research effort between academia and the private sector. Therefore, in the future, it is expected that this country will continue to lead these VP applications.

3.2. Analysis of Results by Topic of the Papers

This section presents and analyzes the results of this bibliographic review considering: (1) type of VP tool used, (2) type of infrastructure project, and (3) life cycle stage of the projects. Figures in this section represent the temporal distribution of the reviewed contributions. The X and Y axes of these figures represent the number of works and the year, respectively. The percentages presented in the analysis of the figures relate to the number of reviewed papers.

Figure 6 presents the distribution of the reviewed papers considering the VP tools and BIM software used by these studies. These figure groups the reviewed publications as follows: (1) Publications that used Autodesk Revit-Dynamo software (red bars). (2) Studies that applied Rhinoceros-Grasshopper software (blue bars). (3) Works that used the API-Python platform (green bars).

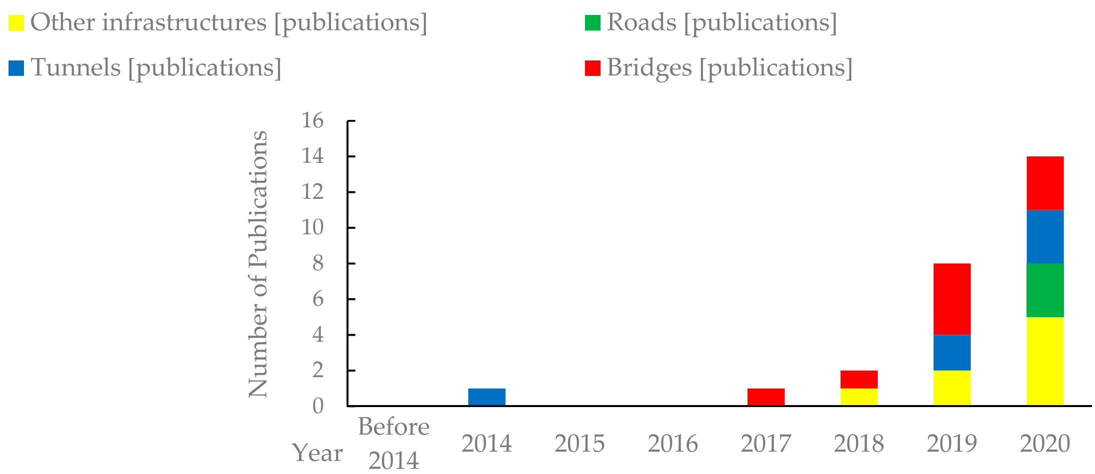


Year	Before 2014	2014	2015	2016	2017	2018	2019	2020
Python - API [papers]	0	0	0	0	0	0	1	1
Grasshopper - Rhinoceros3d [papers]	0	0	0	0	0	1	0	2
Dynamo - Revit [papers]	0	1	0	0	1	1	7	11

Figure 6. Distribution by type of VP tool and BIM software used in the reviewed works.

The data in Figure 6 show that the contributions of the VP tools to this review are: (1) Dynamo, 21 works (80.77%); (2) Grasshopper, 3 publications (11.54%); and Python with 1 study (7.69%). These statistics indicate that the Dynamo tool was the most used by the reviewed publications. Another trend associated with this VP tool is that the annual production in 2018 and 2019 was 2.33- and 3.67-fold more than the total number of works associated with this tool in the 2014–2018 period (three papers). Therefore, an increase in these annual production rates is expected in the future. However, the publications associated with Dynamo indicate that the BIM models used Autodesk Revit as host software, which is not focused on civil engineering projects. This suggests that the interoperability among VP tools has undergone less development compared with that presented by BIM software such as AllPlan Bridge, Autodesk Infraworks, Tekla structures, and Bentley Systems. Further research into this gap would improve the decentralization of the VP tool market for civil engineering by increasing technology transfer among VP tool development companies.

Figure 7 presents the distribution of the reviewed publications by type of infrastructure project. This figure classifies the publications into the following categories: (1) bridges (red bars), (2) tunnels (blue bars), (3) roads (green bars), and (4) other infrastructure (yellow bars). This last project category groups those studies that only contribute with publications that are not part of the leading groups of infrastructure reviewed (bridges, tunnels, and roads).

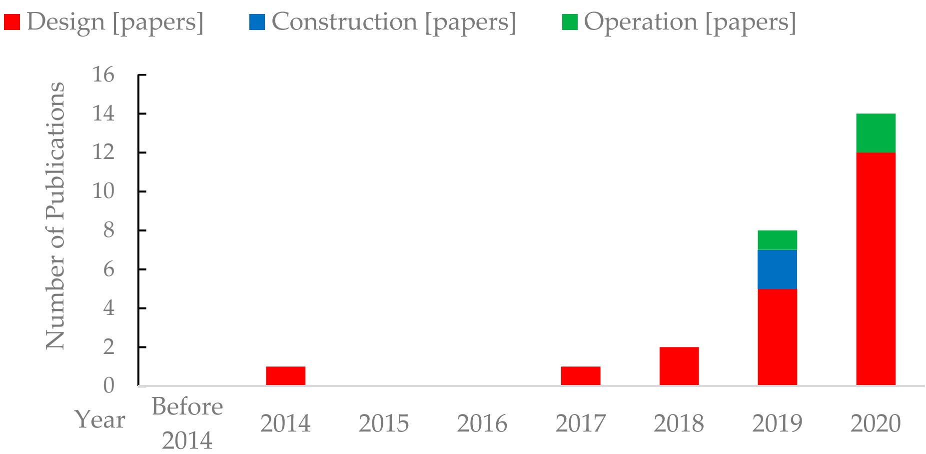


	Before 2014	2014	2015	2016	2017	2018	2019	2020
Bridges [publications]	0	0	0	0	1	1	4	3
Tunnels [publications]	0	1	0	0	0	0	2	3
Roads [publications]	0	0	0	0	0	0	0	3
Other infrastructures [publications]	0	0	0	0	0	1	2	5

Figure 7. Distribution of publications reviewed by type of infrastructure project.

The data in Figure 7 show the following statistics by infrastructure category: (1) Bridges; the leading discipline with nine publications (34.62%). These statistics may be explained because bridges are infrastructure with elements of very complex geometry [128,129], such as abutments, piers, and girder sections, which are challenging to model. VP algorithms have optimized these difficulties by reducing the complexity of their modeling. The studies focused on the application of VP tools to bridges include that of Zhang et al. [115], who modeled the bridge pier design using Dynamo scripts to automate the geometry modeling. Then, the 3D model of the structure was modeled through an extrusion command. Wang et al. [123] generated a BIM parametric model to design railway bridge platforms using Dynamo algorithms. This parametric model reduced the geometric uncertainty during the transversal layout of this bridge typology. Sha et al. [114] designed an algorithm for parametrizing highway-type bridge pedestrian platforms considering both the geometry and possible construction scenarios. (2) Tunnels; These infrastructures made the third-highest contribution with six papers (23.08%), and included that of Zhu et al. [110], who designed a parametric model in Dynamo to study the central axis deviations in tunnels during their transversal construction. This model was applied during the design and construction of a Ningbo province subway (China). Mu et al. [121] developed a Dynamo algorithm that parameterizes tunnel structural support geometry by exporting topographic points and structural values to a BIM model. This algorithm had the main advantage of automating the generation of integral model tunnel design. Liu et al. [130] designed a parametric multi-modeling method for mining tunnels. This invention enables the centralization of the information from several BIM models using Dynamo algorithms and a local data server. (3) Roads; These were the type of infrastructure with the lowest contribution to this review, with three publications (11.54%). This is explained because all of this group's reviewed papers correspond to the year 2020. Therefore, VP tool applications on road projects are still in an early development stage. These applications will depend on the degree of automation that this type of infrastructure requires in the future. The following road project studies are highlighted: Tang et al. [111] generated a parametric model in Dynamo to design the geometry of the roads and for pavement deformation analysis. This parametric model was applied in a road project that connected the cities of Phnom Penh and Sihanoukville (Cambodia). Zhang et al. [115] designed a parametric model in Dynamo to automate the generation of construction platforms during road design. In this manner, the connection in the early stages between construction and design projects was studied simultaneously. (4) Other infrastructures; This infrastructure category made the second-highest contribution to this bibliographic review, with eight publications (30.77%). According to Figure 6, this type of infrastructure experienced constant growth in the number of papers during 2017–2018. VP applications are expanding towards a more significant number of infrastructure types, which has improved the versatility of these tools. The types of infrastructure associated with this category were historical remodeling projects (two studies), energy development (two studies), structural analysis (two studies), construction project excavation works (one study), and parametric modeling of urban electrical networks (one study). The comparison between Figures 6 and 7 shows that in 2018 and 2019, the distribution of publications was not focused on any type of infrastructure project. However, this development was mainly undertaken in the Dynamo tool. This fact demonstrates the versatility that this VP tool offers to civil engineering projects. Therefore, future development of other VP tools should consider both the interface and the execution mode of Dynamo scripts.

Figure 8 presents the reviewed studies' distribution detail considering the stage of the life cycle in which the VP tools were studied. In this figure, the publications are grouped into the following stages: (1) Design of projects (red bars), (2) Analysis of construction projects (blue bars), and (3) Infrastructure operation assessment (green bars).



Operation [papers]	0	0	0	0	0	0	1	2
Construction [papers]	0	0	0	0	0	0	2	0
Design [papers]	0	1	0	0	1	2	5	12

Figure 8. Distribution of the reviewed studies by life cycle stage of the infrastructures.

The analysis of Figure 8 shows that 80.77% (21 studies) of the reviewed publications developed applications in the design stages, 11.54% (three studies) in infrastructure' operation, and 7.69% (two studies) in construction projects. These results indicate that the parametric longitudinal design of BIM projects through VP tools is the main application found in this review. However, these tools have limited scope in developing applications to reduce repetitive processes or generate data bridges between sensor networks and BIM models. Therefore, BIM research should focus on increasing the effort applied to these limited applications to improve infrastructure projects' automation. The topics covered in the papers associated with the operation and construction of infrastructure projects were the development of inspection systems, for both bridges [99,131] and roads [96], and the evaluation of construction work scenarios [70,116]. Although these applications covered many scenarios, as expected from the operation of these infrastructures, they was not found in other VP applications such as: (1) automated estimation of operational road emissions using VP algorithms that transfer real information on traffic and the vehicle fleet; (2) measurement of control variables in bridge assembly using low-cost sensors with subsequent reading and updating of BIM models [132,133]; and (3) automated review and checking of infrastructure multi-models during proposal evaluation stages [134,135].

Table 5 presents a summary of the reviewed publications indicating the type of project, the life cycle of the infrastructures studied by the publications, and the VP tool–BIM software used. The purpose of this table is to facilitate the bibliographic search of future investigations of VP applications on civil engineering.

Table 5. Classification of reviewed publications according to project type, tool used, and the life cycle stage.

Project Type	Life Cycle Stage	VP Tool-BIM Software	Reference
Bridge	Operation	Python-API	[99]
	Operation	Autodesk Dynamo-Revit	[131]
	Design	Autodesk Dynamo-Revit	[23]
	Design	Autodesk Dynamo-Revit	[118]
	Construction	Autodesk Dynamo-Revit	[116]
	Design	Autodesk Dynamo-Revit	[92]
	Design	Autodesk Dynamo-Revit	[122]
	Design	Autodesk Dynamo-Revit	[94]
	Design	Autodesk Dynamo-Revit	[123]
Other infrastructures	Design	Grasshopper-Rhinoceros	[108]
	Operation	Autodesk Dynamo-Revit	[132]
	Design	Autodesk Dynamo-Revit	[109]
	Construction	Grasshopper-Rhinoceros	[98]
	Design	Autodesk Dynamo-Revit	[112]
	Design	Grasshopper-Rhinoceros	[113]
	Design	Grasshopper-ArchiCad	[100]
	Design	Autodesk Dynamo-Revit	[124]
Tunnels	Design	Autodesk Dynamo-Revit	[101]
	Design	Autodesk Dynamo-Revit	[110]
	Design	Autodesk Dynamo-Revit	[93]
	Design	Autodesk Dynamo-Revit	[130]
	Design	Autodesk Dynamo-Revit	[120]
	Design	Autodesk Dynamo-Revit	[121]
Roads	Design	Grasshopper-Dynamo	[97]
	Design	Dynamo-Python	[111]
	Design	Python-API	[116]

The results of this review show that the potential research lines (trends) of VP tools in infrastructure projects are as follows: (1) Automation of the design of infrastructures: Parametric design is clearly the main application of VP algorithms in the literature. VP tools have been used for the automation of the design of a number of infrastructure elements in the literature (such as bridges, roads, and tunnels). In the future, it is expected that these tools will be also applied for the parametric automation of the design of a growing number of infrastructure projects. Nevertheless, these publications have focused on the automation of the longitudinal design of bridges, roads, and tunnels. This situation has generated a critical gap in the design of specific elements, such as abutments, foundations, or reaction frames for tunnel boring machines. (2) Interoperability with Web applications: The generation of virtual clouds that support BIM information models will be an important trend in projects' digitization because this can be used to manage and generate automatic information for evaluating and assessing BIM processes. Therefore, it is highly likely that VP algorithms will improve the compatibility of their VP language with that of Web servers. (3) Monitoring of infrastructure operation: Due to the advantages of VP related to including information in BIM Models, it is likely that these tools will be further developed to enable an easier and more efficient communication with the monitoring of the infrastructure on site.

4. Conclusions

This paper studied the application of visual programming tools in infrastructure projects. For this purpose, the state of the art of these algorithms is systematically reviewed. To encourage engineers and scholars to use VP algorithms, the benefits and the future research trends of these tools are also detailed.

This bibliographic search verified that VP tool applications have been focused on architecture projects rather than infrastructure. However, the application of these tools in civil engineering projects is growing. Therefore, the automation gap between building and infrastructure projects is being reduced.

This bibliographic search reviewed 26 publications with a distribution of 13 registered patents and 13 academic papers. The most-used VP tools were Dynamo for Autodesk (21 publications), followed by Grasshopper (three publications) and Python, with two publications. This suggests that the interoperability among the studied VP tools has undergone less development than the connectivity between different BIM software packages. In other words, although the market for BIM software offers better infrastructure modeling tools than the Autodesk Revit software, VP tool applications have continued to be developed predominantly in Dynamo.

Regarding country contributions to this review, China was the largest contributor. Moreover, all the reviewed patents and the majority of academic articles were also produced by China. However, a significant contribution was also made by European publications. These results suggest that the current research on VP tool applications in infrastructure has strong potential in both geographic zones.

The parametric design of bridges and other infrastructure projects is the main research topic. Furthermore, companies have concentrated their research efforts on developing registered patents for bridge design projects due to their economic potential. However, a significant research gap is the application of VP tools in road and tunnel projects, because the number of works that studied these infrastructures projects is limited.

The parametric design of infrastructure projects was found to be the leading application of the VP tools. However, the operation and construction stages also present interesting applications. The number of associated publications is much lower than that for parameterization. The topics of analysis of emissions, control of variables by sensors, and validation of BIM infrastructure models are proposed as potential applications of VP tools for the future.

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