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Review

Bibliometric analysis of Building Information Modeling, Geographic Information Systems and Web environment integration

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A R T I C L E I N F O

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A B S T R A C T

The integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) within the Web environment is a promising approach that greatly enhances the capabilities of the aforementioned environments through the wide range of technology solutions used on the Web. This paper aims to reveal the trends of research in BIM, GIS, and Web integration and discuss the challenges and potential opportunities of such integration in terms of the most common uses in construction. The bibliometric analysis used as the method, compared to conventional literature reviews, reduces the likelihood of subjective judgments. The methodology used is based on a set of five research questions. To answer these, bibliographic coupling is used to analyze the publications datasets, specifically, co-citation networks, co-authorship networks, and the co-occurrence map of keywords. This review contributes to the field in raising awareness of the knowledge composition of BIM, GIS, and Web integration in the last decade, dominant research topics, the most recent trends, and the most pressing issues and use cases analyzed in the current studies related to BIM, GIS, and Web integration, thus identifying gaps and defining future research areas on the topic. The research shows that the number of developments focusing on BIM, GIS and Web integration has been continuously growing with a sudden increase after 2016. The study also revealed that the research work in this area consists of disjointed and fragmented research studies and has been conducted mainly in isolated clusters. Gaps and critical areas for future research include BIM, GIS, and Web interoperability solutions, standardization, BIM model processing and performance optimization, data exchange and storage.

1. Introduction

Rapid technological advancements and intense competition in the construction sector are driving a significant shift in the way construction projects are developed and implemented. The process of automation and digitalization of construction processes is triggering an opportunity to replace traditional practices with new ways of accomplishing construction projects. Building Information Modeling (BIM) is considered an important methodology in the construction field in the last decade because BIM technologies bring many advantages into the life cycle of a construction project [1–3]. Project modeling allows the workflow to be optimized, determines the best ways of project development, and can include all types of analysis for achieving a better result. BIM has grown from the usual 2D drawings and 3D models and become an advanced approach to store and analyze information on all construction elements [4]. Such an approach make it possible not just to construct a horizontal and vertical object more efficiently, but to analyze the project in different conditions, compare several alternatives for the project's systems and other building elements, and predict situations that can influence the environment and human life.

Where human activities are happening in specific spaces, integrating geospatial data into the design process brings many benefits. Geographic Information Systems (GIS) represent different aspects of the real world in the condition of the digital environment, starting from the variety of geodesic information in differing coordinate systems and ending with infinite data sets with a real-time update. GIS technologies have evolved significantly over the last decade. Technologies such as the 3D mesh model extend opportunities for real-world digitalization and allow a representation of the real environment that can be used in all kinds of analysis. The connection of data sets provided by remote sensors with real-time updates allows the actual situation of any sphere of human activity to be visualized. Inventing the Internet of Things (IoT) brings a

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new way of collecting data from the real-world and processing it with higher performance and better results. GIS is considered a significant component that supports the decision-making process in construction, allows the most effective contribution from each participant in the design process, and extends the visualization capabilities and analysis.

BIM processes information about construction projects and their internal components that are considered micro-level data, and GIS represents information about the large-scale environment such as topography, which is at a macro-level [5]. The integration of BIM, GIS, and the Web allows all project participants to manage the project more efficiently, share information through the internet with real-time updates, effectively communicate and work on the same data simultaneously, better coordinate actions, and make better decisions related to each stage of the project development [6]. All the abovementioned can be accomplished within the 3D city model that represents the real environment.

GIS is widely used to analyze information and visualize buildings and linear infrastructure, with contextual data including environmental, demographic, structural, and other information [7].

The most usual use cases of BIM, GIS, and Web integration can be highlighted as project management [8–10] and analysis [11,12]. However, such integration faces a large number of obstacles because BIM and GIS have dissimilarities, such as the different scales of the information, differing development stages, and varying semantic and geometric information [13]. These differences bring many challenges for researchers focusing on integrating these fields, and the biggest problem is a lack of standards, technological solutions, and methods [6]. Some researchers are trying to fill this gap with different kinds of new data standards or to translate the existing standards. For example, Aien [14] introduced InfraGML for land usage, Laat [15] proposed GeoBIM to solve the issues related to BIM and GIS interoperability, Lee [16] used the Web environment to store the information about BIM model objects in a database based on IFC, XML, FBX and CityGML formats. Other obstacles are related to the limited capabilities of the Web environment, as the Web was developed with a completely different purpose than BIM and GIS. For many years, GIS-focused studies were developing technologies and tools for bringing GIS into the Web environment, which resulted in converting paper maps into digital maps and databases. The BIM environment did not undergo high-level developments in the Web, so BIM still does not have as wide a range of opportunities as GIS within the Web environment, for instance no BIM native file types support [17] and a need for conversion [6], execution issues [18], a lack of unified standards [19], and a lack of tools and methods [20]. As a result, BIM project participants do not have the opportunity to create or edit native BIM models within the Web environment or perform BIM native analysis; moreover, the visualization and inspection of BIM model representation still need a list of issues to be solved. Additionally, the Web environment does not have decision-making systems that can comply with the requirements of the project participants, i.e. productivity and quality improvement, project cost reduction, safety control [21].

In light of the aforementioned, the main aim of this review is to summarize the trends of BIM, GIS, and Web integration in the construction industry and discuss the challenges and potential opportunities of BIM, GIS and Web integration in terms of the most common use cases in construction.

The present review contributes to the field in raising awareness of:

1 The knowledge composition of BIM, GIS, and Web integration in the analyzed 10 year period.
2 Dominant research topics and the most recent trends of integrated applications of BIM, GIS, and Web technologies in the construction field.
3 The most pressing issues and use cases analyzed in recent studies related to BIM, GIS, and Web integration.
4 Identifying gaps and defining future research areas on the topic.

The remainder of the manuscript is organized as follows: Section 2 presents the information about scientific articles related to the topic of the research, including reviews of the manuscripts, discusses the main focuses and issues, and defines the main research questions. Section 3 describes the research methodology and tools used for the analysis. Section 4 presents the results of the analysis and defines the answers to the research questions. Section 5 provides the conclusions and summarizes the results.

2. Previous studies related to BIM, GIS and Web environments integration

The integration of the BIM, GIS, and Web environments is a complicated process that involves technological solutions and methods for solving interoperability issues between the above-highlighted environments. The integration process considers the Web environment as the dominant environment, into which the other two are integrated. The interaction of BIM and GIS environments became a hot topic in the construction field in the last decade, in the same way that each field's individual development has moved towards new technological solutions and methodologies. The main obstacles arising in BIM and GIS integration are the different scales of their environments, their various coordinate systems, unique semantic and attributive information, individual geometric information and particular approaches to information storage, and dissimilar methods of information management and access [13]. In the last decade, researchers have investigated this field and developed several main concepts of BIM and GIS interaction within the Web environment.

One of the concepts recently explored, called Smart City, brings the opportunity for engineers to perform a new and efficient analysis in the condition of a real environment representation model. For instance, for monitoring and visualizing the energy consumption for smart green city development, Kim, Shin, Choe, Seibert and Walz [22] developed a WebGL web-based system that includes GIS information from Google Map API. Such researches are important for urban planning and civil engineers, because they make it possible not just to analyze real environment conditions and improve operations across the city, but to develop and implement automated control solutions of parts of the city, including BIM model representations. To control such automated solutions they need to provide information about their status and surroundings. For this purpose, the Internet of Things has been introduced.

The Internet of Things (IoT) is used for real-time monitoring, analysis, and control of complex systems of sensors, distributed systems, and mechanisms to develop a common operating picture (COP) [23]. The research by Gao, Ali, and Mileo [24,25] should be mentioned among the most recent and noteworthy in this field. Their articles mainly focus on the Internet of Things, the semantic web and environmental analysis. Puiu et al. [26], and Kolozali et al. [27] describe the CityPulse framework that provides the tools and opportunities to create smart city services based on real-time data sets. Apart from information processing and visualization, the framework enables a different kind of analysis to be performed and aids decision-making [26]. CityPulse does not support BIM model implementation as such functional was not developed; however, it includes visualization presented as a 3D map based on a range of sensor information. The other most well-known solutions for indoor mapping and wayfinding for Smart Buildings are Indoorway [28], Mapwize [29], and MapsIndoors [30]. The integration of the BIM model into similar projects, as highlighted above, can bring a long list of benefits to the construction field, such as performing analysis in real environment conditions based on actual data, building components control, and online building inspection. With the integration of BIM and IoT, the digital twin concept was introduced.

The digital twin is a virtual model with comprehensive physical and functional capabilities as a real object [31]. The concept of digital twinning expands the analysis in actual existing environment conditions by the ability to predict the object behavior based on simulation results using real data provided by sensors [32]. The most outstanding project that aims to use the digital twin concept is Virtual Singapore [33], developed by the National Research Foundation, where the data presented in the project is related to the real world, including information from government agencies, infrastructure, and transport, components of the buildings, land attributes, and other data. Such developments improve the transparency of the decision-making process, data accessibility, the sustainability of urban development, enable various analyses, improve disaster detection, simulation and prediction, and much more. Other important information that can be processed in such conditions is the human position and behavior as this information can save lives in the case of emergencies.

Many authors [34–39] are focusing on determining the human position through the use of various devices and sensors with the purpose of automated analysis on a variety of BIM use cases, such as accessibility, security, safety. Due to a range of decisive factors and situations, most of the presented solutions and platforms are mainly focused on resolving wayfinding problems. However, it is critical to continue research in this field because such automated solutions can save many human lives in the case of a disaster or unexpected situations, such as earthquakes, flooding, or fire alarms. The synergy of BIM and IoT is useful and efficient because it extends the usual ways of gathering and mapping the data from a construction project to the BIM model. This integration should include not just visualization of the semantic information inside the BIM model but its analysis in the condition of existing objects including the mechanisms. Some scientific studies [8,9] concluded that the practical implementation of IoT with a BIM model is a complicated process due to a lack of standards and interaction methods; therefore, they presented new methods for the management of the construction process lifecycle, including information exchange standards and practices. Teizer [10] presented an approach to increase workplace safety and provide real-time feedback to employees by ensuring connection to the indoor environment using Bluetooth and RFID sensors. Although many researchers in this field are focusing on the development of concepts and methodologies for BIM and IoT interoperability, not many projects aiming at the practical implementation of these solutions have achieved satisfactory results. The linking of the data gathered from sensors with the analytical systems based on Web technologies is called the semantic Web. The World Wide Web Consortium (W3C) determines this type of technology as the Web of Things (WoT), the main aim of which is to enable the easy integration of metadata, interfaces, mechanisms, systems, and platforms [40]. The semantic web technologies have proved their efficiency in many different fields, such as geology, agriculture, medicine, and the automobile industry. The results of BIM integration with other environments bring more and more use cases of the BIM in the building life cycle every year, and the number of related scientific publications is rising respectively.

The integration of the BIM model into the Web environment faces a large number of issues. The main problem is that BIM file types can not be processed in the Web environment [17,41,42], which forces developers to perform a complicated process of BIM model conversion to enable the transfer of geometric and attributive information [43]. Even the widely used model exchange format Industry Foundation Classes (IFC) [44] is not able to store all the relevant semantic information for BIM model objects and construction processes [45] to be processed inside the Web without extra conversions. This means that just the representation of the BIM model can be processed, but not the original model. Amirebrahimi, Rajabifard et al. [46] conducted an overview of BIM and GIS integration with semantic web technologies at the process level, including frameworks of IFC and CityGML integration [47,48], focusing on Open Geospatial Consortium (OGC) standards [49]. The authors highlighted that the use of LandXML [50] and IndoorGML [51] can solve some interoperability issues. The most promising technologies are Unified Modeling Language [52,53], and the Quartierdaten-Management system [54], the aim of which is the representation of the attributive and geometrical information.

Difficulties also arise in BIM model visualization because of the big file size and data complexity [18]. In the GIS environment, this issue is solved using 3D tilesets [55], such as Batched 3D Model (b3dm); however, such a solution is not a common for visualization of the BIM model representation. If one dives deeper into the processing of the BIM model representation within the Web environment, then the lack of tools and methods can be seen [20]. As a result, it is hard to analyze BIM model data within the Web environment. For instance, Niu, Pan and Zhao [6] have used a complex solution of transferring energy data from the Autodesk Revit gbXML file format to IDF file format and after that to the Web supportable Collada file type. Their results revealed that differences in standards and data structures are among the most critical and challenging issues with the integration of GIS, BIM and Web. Irizarry and Karan [56] implemented the integration of BIM and GIS environments and developed a visualization method to improve the monitoring of supply chain management. However, the proposed approach had several limitations, and the conclusion assumed a future focus on providing interoperability at the semantic level for ensuring full integration of the BIM and GIS.

The number of projects related to the automation of construction project processes has increased in recent years, and involved new technologies. Many new methods and systems have been developed and introduced with the purpose of automated analysis, capturing, and processing of the project data. The main aim of the developed systems is to improve efficiency, reduce carbon emissions, improve logistics, safety, and other aspects of the construction project. Navon and Sacks [57] concluded that adopting such automation in construction processes is still not very advanced nowadays, and more research should be carried out in this field. Chang and Chen [58] mentioned that the construction industry has a high dynamics of developments and the use of automation systems on the construction site is not always appropriate. Therefore, they proposed a solution for monitoring the construction stage of the project based on the GIS system with the use of barcodes.

The literature analysis revealed that existing studies have added value and expanded the knowledge of BIM integration with GIS and the Web, but also that many challenges and the need for further research in this field are reported. A list of the main review studies published between 2010 and 2020 that refer to BIM integration with other environments is presented in Table 1. As illustrated in the table, no bibliometric review study has been published that focused on the integration of the BIM, GIS, and Web environments in a complex way.

Table 1 shows that most of the reviews aimed to analyze the BIM and GIS integration [5,59–61,64,68,69], some are related just to BIM technologies [21,62,63,65,66], and a few reviews aim to analyze the state-of-the-art related to BIM integration with the Web [67] or augmented reality [66]. However, the performed analysis revealed that all above-highlighted reviews partly describe the technologies and methods that are related to the integration of all three environments, such as the semantic web, IoT, data transfer, and server-side-based solutions. This observation allows to conclude that it is necessary to have comprehensive information about the integration of the BIM, GIS, and Web environments.

The existing studies cannot be considered exhaustive because they do not provide complex information about the integration of all three environments; therefore, they cannot represent the development trends and state of development around the globe, or most importantly, predict the direction of further research related to integration of all three environments. For researchers, it is important to know the actual situation, the research trend, and the gaps in this field in order to have an opportunity to decide in which direction they should focus their investigations.

With the above in mind, the main aim of this review is to summarize the trends of BIM, GIS and Web integration and discuss the challenges and potential opportunities of BIM, GIS and Web integration from the perspective of the most common use cases in construction.

This leads to the following main research question (RQ):

Table 1
Summary of the main reviews focused on BIM integration with other environments.

Source	Year	Review period	Database, type of documents	Number of papers	Research method	Scope
[59]	2015	2006–2015	Not provided: journal papers, conference proceedings	44	Systematic review including research trend, journals analysis, integration approaches, main focuses	BIM-GIS integration, climate adaptation, shadow effect analysis, utility visualization, facility management, location and space navigation, planning, natural disaster damage analysis
[60]	2017	Not provided	Not provided: journal papers, conference proceedings	141	Systematic analysis: integration approaches	BIM-GIS integration, dissimilarities and mismatches, conversion process, integration at data level: standards and methods, integration at process level: semantic web and services-based methods, integration at application level. Comparison of integration solutions
[5]	2019	2008–2018	Web of Science: journal papers, conference proceedings	76	Bibliometric analysis including research trend, journals analysis, co-occurring keyword analysis, co-authorship analysis	BIM-GIS integration in the sustainable built environment, applications integration, future trends of development
[61]	2018	2004–2014	Scopus and Google Scholar: all types of papers	149	Systematic analysis: journal analysis, author analysis, integration approaches	BIM-GIS integration with IoT and virtual reality for facilities management, uses cases, IoT, reality capture technology
[62]	2017	2005–2016	Web of Science: journal papers	614	Scientometric analysis: research trend, co-authorship network analysis, countries network analysis, institutions network analysis, co-occurring subject categories analysis, co-occurring keywords analysis, journal co-citation network analysis, authors co-citation network analysis, documents co-citation network analysis	Global BIM research, BIM technologies
[21]	2020	2000–2016	Scopus and Web of Science: journal papers, conference proceedings, reviews, book chapters	5418	Bibliometric analysis: research trend, relative growth rate, doubling time, countries analysis, authors comparison, organizations comparison, citation analysis, keywords analysis, main focuses	Decision support systems in construction, building information modeling (BIM); sustainable development; artefact modeling
[63]	2020	2010–2020	Scopus: journal papers, conference proceedings	885	Scientometric analysis: research trend, countries analysis, co-occurring keywords analysis	BIM technologies, radio frequency identification devices, global positioning system, Internet of Things, sensors, augmented reality, virtual reality, laser scanning, artificial intelligence, 3D printing, robotics
[64]	2020	1975–2019	Web of Science: journal papers, conference proceedings	2848	Systematic analysis: publication analysis	BIM-GIS integration for heritage modeling, point cloud, information management, ontology
[65]	2020	2010–2019	Scopus: journal papers, conference proceedings	240	Bibliometric analysis: research trend, publication type analysis, countries analysis, co-authorship network analysis, co-occurring keywords analysis, focuses analysis	BIM technologies, safety management in construction, visualization and image processing, project monitoring, information management, internet of things, automation system, robotic system, health and safety and accident prevention, structure evaluation
[66]	2020	2008–2018	Web of Sci-ence, SciSearch, SCOPUS, INSPEC, Google Scholar, Aca-demic OneFile, EBSCO, OCLC, VINITI, SCImago, ProQuest	64	Systematic analysis: journals analysis, areas of activities analysis, trends analysis	BIM and augmented reality integration, inspection and visualization, building maintenance, assembly of building systems, infrastructure, trends related to augmented reality technologies
[67]	2017	Not provided	Set of journals from Web Of Science: journal papers	–	Qualitative assessment analysis	Web technologies in the AEC industry, interoperability, standards, conversion, linking across domains, collaborative information management, building performance analysis, regulation compliance checking, geographical and infrastructure data
[68]	2017	2008–2017	Web of Science: journal papers, conference proceedings	96	Research trends, countries analysis, jounals and conferences analysis	BIM-GIS integration in AEC industry, use cases
[69]	2017	Not provided	Web of Science and Engineering Village	41	Research trend, platform distribution	BIM-GIS integration. Application object distribution: infrastructure, urban district, building

What is the current state of research in BIM, GIS and WEB integration related to the most common uses in construction?

According to the main RQ the following two categories of RQs are defined:

RQ-1: How well is the research field related to BIM, GIS and Web integration investigated?

RQ-2: What is the development tendency of BIM, GIS and Web integration?

RQ-3: What is the state of developments in BIM, GIS and Web integration solutions around the globe?

RQ-4: What are the most pressing issues and use cases analyzed in the recent studies related to BIM, GIS and Web integration?

RQ-5: What is the direction of further development in BIM, GIS and Web integration?

The answers to the research questions are given in Section 4. Specifically, the answer to RQ-1 is given in Section 4.1; the answer to RQ-2 is given in Section 4.2; the answer to RQ-3 is given in Section 4.3 and Section 4.4; the answer to RQ-4 is given in Section 4.5; and the answer to RQ-5 is given in Section 4.6.

3. Research methods

To perform an analysis of the existing scientific articles about BIM and GIS integration into the Web environment the research methodology based on the research scheme presented in [70,71] has been applied. The steps of the research process are presented in Fig. 1.

Step 1: Defining the scope of the study. This step aims to examine the existing scientific papers and determine the BIM, GIS and Web environments integration related documents where such integration can be performed. The main research question in this step is "*What is the current state of research in BIM, GIS and WEB integration related to the most common uses in construction*?"

Step 2: Defining the search sources. To perform this search, the Web of Science (WOS) Core Collection database was selected as it contains a large number of journals and scientific articles mostly in the English language.

Step 3: Compiling the search query based on boolean operators and combining related definitions and keywords: "BIM", "GIS", "Web". To receive a more accurate result "Smart City" keyword was included in the BIM boolean part of the query. With the same purpose, "Internet of Things" was included in the GIS boolean part, as every IoT project has a GIS component in it. The resulting query is: (("BIM" OR "Building Information Model*" OR "Smart City") AND ("GIS" OR "Geographic Information Systems") AND ("Web*" OR "web-based" OR "World Wide Web" OR "semantic web" OR "IoT" OR "Internet of Things")).

Step 4: Performing the search. This step contains the search and collecting, exporting and saving the resulting information for further analysis. In this step, a searching process is performed according to the query defined in step 3. The results of this research are presented in Fig. 2.

Step 5: Search results filtering. The search results obtained from the scientific core database defined in Step 2 contain all types of information, and not all of it is suitable for the research topic of this article. Therefore, the results need to be inspected and filtered, which is done using the following parameters: type of the document, publication year, and subject areas.

Step 6: Bibliometric analysis of the search results. Such an approach minimizes the subjective judgment of the author [72] since analysis is based on the data retrieved from the database, and no author influence can be applied at any point of the analysis process. The bibliometric analysis contains the next categories: number of publications, year of publication, countries, institutions, journals, authors, author's keywords, main groups of keywords.

Various tools exist for bibliometric data visualization and analysis such as VOSviewer, CiteSpace, BibExcel, and VantagePoint [62,73]. One of the most often used and confirmed in many similar studies as reliable for such analysis is VOSviewer [74]. Therefore, this software tool was used in this article. The idea of this tool is to present the connections of the articles as a network, where nodes represent units of research, such as document, institution, author, journal, country, and keyword; while links represent the connections between nodes. The size of the node and the thickness of the connecting line represents the number of occurrences and the strength of the connections respectively. The nodes with strong connections form clusters [75]. Perianes-Rodriguez, Waltman & Van Eck [76] discussed the difference between the fractional counting and full counting algorithms that are used in the analysis. The full counting algorithm considers the article with multiple authors, institutions or countries as one per each related node, while fractional counting divides one into the number of related nodes. The authors highlight that the difference between these two counting types can have a big influence on the results in cases where a large number of articles are analyzed, and almost no difference when the number of scientific papers is small. In this article, the full counting type has been used.

4. Results

4.1. Number of papers in research field

This article aims to present exhaustive information about the research field and related scientific papers; therefore, an investigation about the number of scientific papers focusing on each environment, specifically, BIM, GIS, and the Web, and their interaction, has been performed. Such investigation allows discussion of the number of scientific papers in the research field. Consequently, this allows to answer the research question RQ-1 (How well is the research field related to BIM, GIS and Web integration investigated?).

The search query that is presented in Step 3 of the Research Methods section has been used to gather the documents related to each analyzed environment and their interaction.

The results of the overall search (Fig. 2) performed on step 4 shows that the total number of articles is:

- BIM environment: 13,357;
- GIS environment: 65,793;
- Web environment: 461,060;
- BIM and GIS environments integration: 224;
- BIM and Web environments integration: 1273;
- GIS and Web environments integration: 3028;
- BIM, GIS and Web environments integration: 111.

The above results show that integration of the considered environments is discussed in a smaller number of articles compared to the individual ones. The smallest number of studies is those discussing the integration of all the required fields, specifically, BIM, GIS, and the Web, represented by only 111 articles.

For further analysis, only journal articles were selected because they were peer-reviewed and accepted as research with a high-quality contribution to the research field. After applying filters, which are the type of document, publication year, and subject areas, only 52 documents appear to be journal papers published in the decade from 2010 to 2020, and in the relevant subject areas of engineering, decision science, computer science, and multidisciplinary. These documents were used for further analysis.

Taking into account the obstacles and issues discussed in Section 2 of this paper, it is clear that such a small number of scientific research works cannot cover all the gaps in the research field. Therefore, it can be concluded that the process of the integration of the above-highlighted environments is not yet well investigated and requires more research.

4.2. Trend of research

At the beginning of any research, it is important to determine if the research field is of interest in academia and what is the development tendency. The bibliometric analysis reveals this information based on the article's publication year. The chronological distribution of articles in the analyzed period allows us to answer research question RQ-2 (What is the development tendency of BIM, GIS and Web integration?). The number of articles related to BIM, GIS and Web environments integration began to rise starting from 2011, as illustrated in Fig. 3.

Although in the last decade the overall number of publications has not been large, nonetheless, the figure shows a rising tendency that can be considered as a proof of a growing interest in BIM, GIS and Web integration that leads to increasing number of research in this field. This allows us to conclude that there is growing academic interest in this field of research. However, the number of studies on BIM, GIS, and Web integration is still low compared with similar studies in the BIM field. This proves the lack of attention paid to this field of research in the BIM literature.

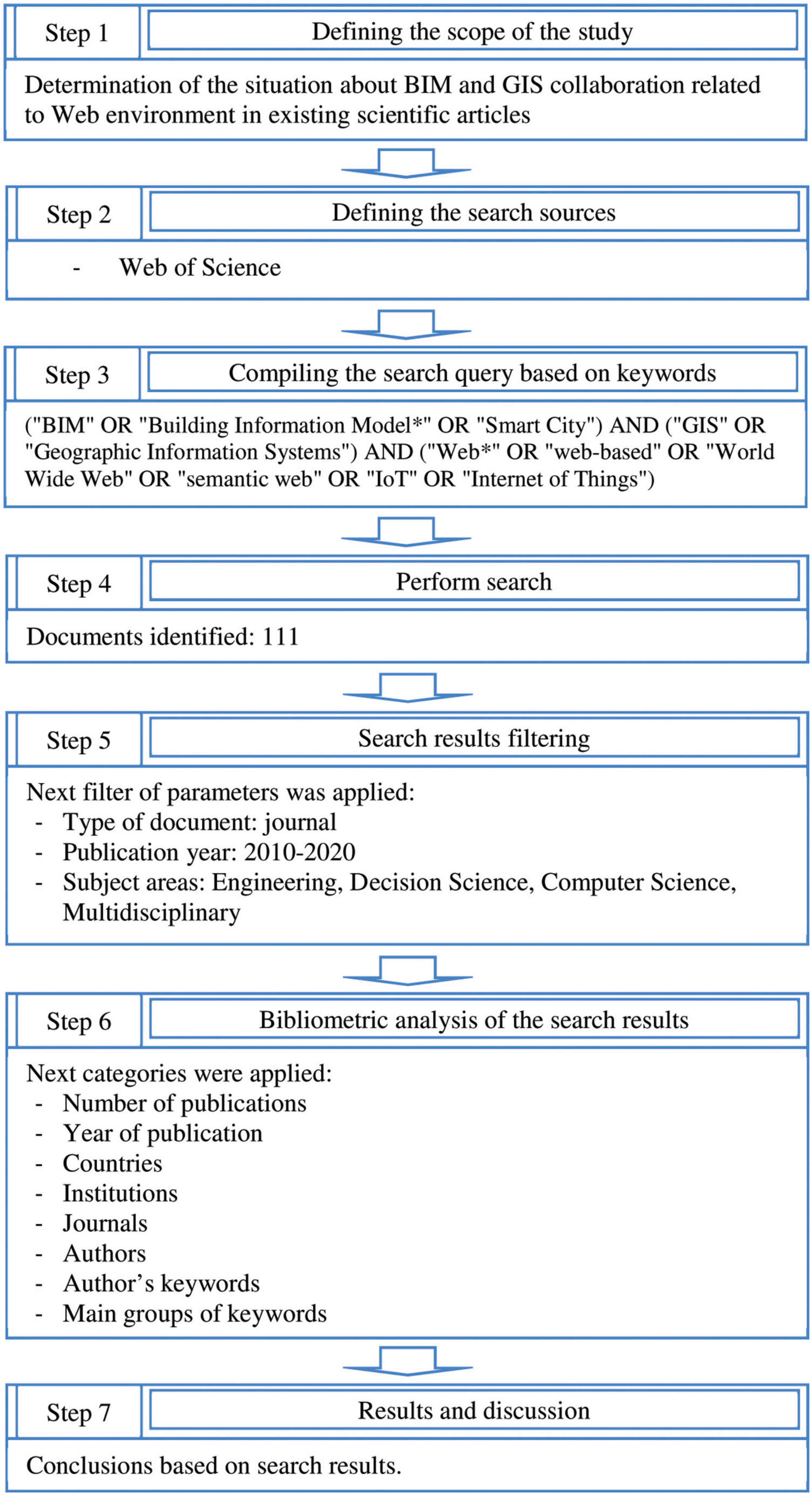

Fig. 1. The research step for bibliometric analysis of retrieved papers.

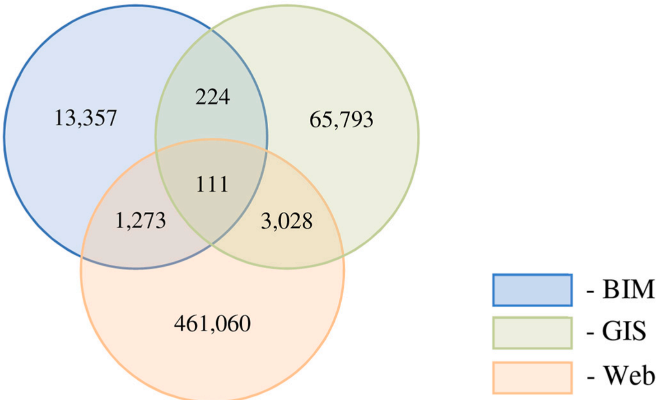

Fig. 2. Overall research about the situation in every related environment.

4.3. State of research and developments in BIM, GIS, and Web integration

Based on co-authorship analysis, a network of the involved countries can be created to determine the regions that are investigating this research field. This analysis aims to determine the contribution made by individual countries and helps to answer the research question RQ-3 (What is the state of developments in BIM, GIS, and Web integration solutions around the globe?). The result of this analysis generated by VOSviewer is presented in Fig. 4.

After applying VOSviewer algorithms, 27 countries involved in the research field since 2011 are identified. Fig. 4 presents the distribution of studies on a time scale. In this analysis, regions with less than one citation have not been included. The countries that first started publishing research about GIS and BIM integration into the Web environments are Austria, Spain, Israel and France, but the number of articles is small. Later, Canada, Sweden, the USA and Finland started publishing the results of their investigations in this field. It is noteworthy that the USA has the biggest co-authorship network. Belgium, Luxembourg and England started publishing research in 2017, and later China, Australia, Italy, Poland, and Wales. It should be highlighted that China has the largest number of documents and a large co-authorship network, but it is

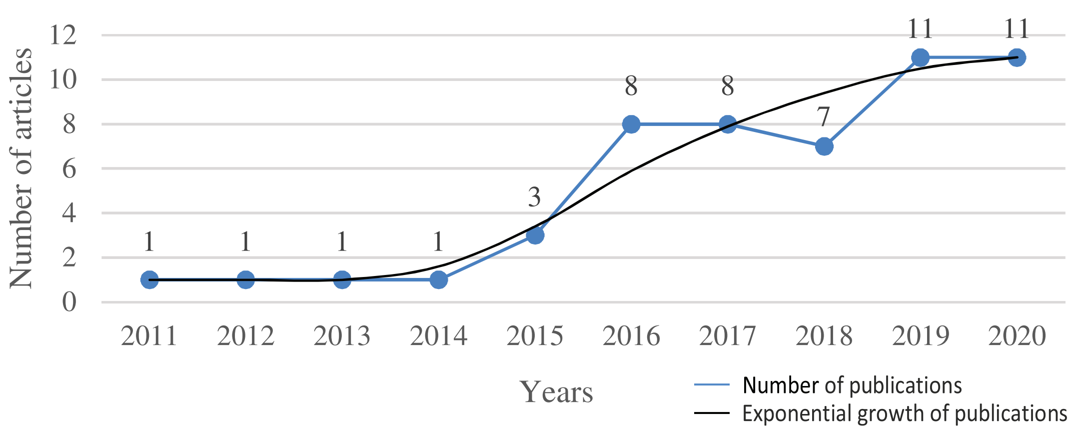

Fig. 3. Number of relevant papers on BIM, GIS and Web integration published in each year between 2010 and 2020.

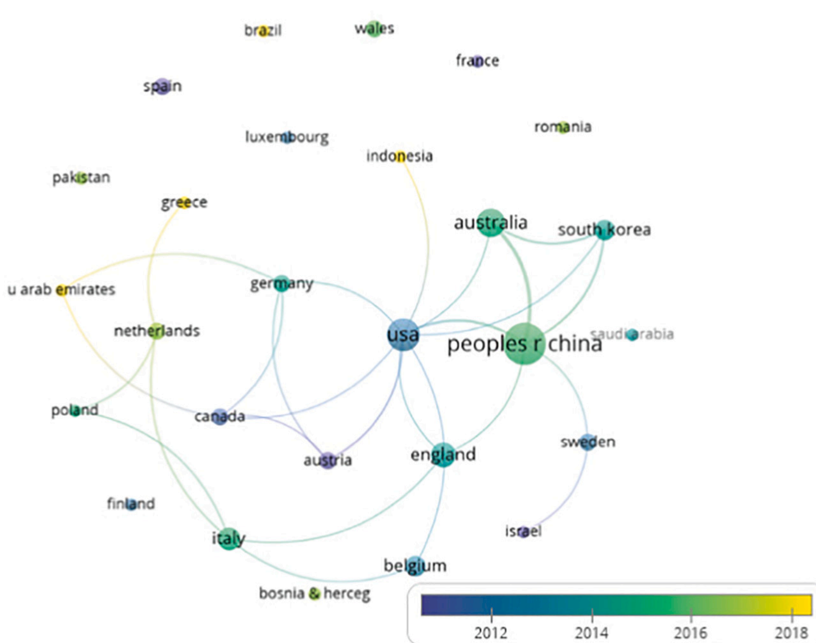

Fig. 4. Co-authorship network of countries according to years with more than 1 citation.

smaller compared to the USA network. The latest countries to start taking an interest in the highlighted fields are Greece, Indonesia, the UAE and Brazil.

Table 2 presents all countries sorted by the number of documents and citations. Countries that have fewer than 5 citations are not presented.

The largest number of scientific research papers is from China (19 articles), with 24% of the total number of published scientific articles and 186 citations or 16.5% of the total citations. The United States only has around half the number of publications (10 articles), which is 13%, but almost twice as many citations (301), which is 26.8% of the total citations. In the third place is Australia, with 7 documents or 9% of the articles, and 97 citations or 8.6% of the total citations. This analysis shows that progress has been made in many countries in contributing to the research field.Other relevant data gathered from the co-authorship network analysis is related to organizations investigating the research field. For this analysis, the "organization" is specified as a unit of co-authorship network analysis. Table 3 depicts the organizations that have more than one article related to the integration of the BIM, GIS and Web environments.

From Table 3 it can be seen that Curtin University, Australia, has the highest number of documents (4). In the second place is the Chinese Academy of Sciences with three articles, and other organizations published two articles on the topic. Interestingly, China and the United States have the same (6) and the largest number of organizations participating in the analyzed research field.

Other important information that researchers are interested in is the scientific journals that are publishing research papers about BIM, GIS and Web integration. To collect this data from the analyzed articles, bibliographic coupling analysis was used, with "sources" specified as a unit of analysis in the VOSviewer tool. For this analysis, journals with at least one scientific paper and more than 20 citations were selected. Table 4 contains the results of this analysis.

The highest number of documents is found in the *ISPRS International Journal of Geo-Information* (10 articles and 118 citations). Then follows *Automation in Construction* with 7 documents and 132 citations. These two journals have an important contribution and can be considered significant in the research field. Third place is shared by 2 journals with just 2 articles, yet *Sensors* has a greater number of citations, with 56, while *IEEE Access* has 49 citations.

The following observations can be made based on the above discussion. First, the research field of BIM, GIS, and Web integration is attracting extensive interest, as many countries and organizations are involved. However, the extent of publication in scientific journals is still not large, as can be seen from the small number of publications on the analyzed topic. The last observation also indicates the slow development of the analyzed field.

Table 2
The most active countries in the research field.

Country	Documents	Citations	Percentage of documents	Percentage of citations
China	19	186	24,4	16,5
United States	10	301	12,8	26,8
Australia	7	97	9,0	8,6
England	5	32	6,4	2,8
Italy	4	8	5,1	0,7
Belgium	3	70	3,8	6,2
South Korea	3	59	3,8	5,2
Austria	2	86	2,6	7,6
Canada	2	54	2,6	4,8
Sweden	2	39	2,6	3,5
Germany	2	32	2,6	2,8
Spain	2	22	2,6	2,0
Wales	2	19	2,6	1,7
Netherlands	2	5	2,6	0,4
Israel	1	39	1,3	3,5
Luxembourg	1	38	1,3	3,4
Saudi Arabia	1	25	1,3	2,2
Finland	1	8	1,3	0,7
Poland	1	5	1,3	0,4

Table 3
The most active organizations, with 2 or more articles.

Organization	Documents
Curtin University (Australia)	4
Chinese Academy Of Sciences (China)	3
Cardiff University (United Kingdom)	2
Delft University Of Technology (Netherlands)	2
Georgia Institute Of Technology (United States)	2
Ghent University (Belgium)	2
Hong Kong University Of Science And Technology (Hong Kong)	2
Kyung Hee University (South Korea)	2
Millersville University Of Pennsylvania (United States)	2
Minist Land And Resources (China)	2
Pennsylvania State System Of Higher Education Passhe (United States)	2
Qingdao University (China)	2
Salzburg University (Austria)	2
Shenzhen Research Center of Digital City Engineering (China)	2
Shenzhen University (China)	2
Southeast University China (China)	2
State University System Of Florida (United States)	2
Universidad De Valladolid (Spain)	2
University Of Calgary (Canada)	2
University Of Florida (United States)	2
University System Of Georgia (United States)	2

Table 4
The most cited journals with more than 20 citations.

Source	Documents	Citations
ISPRS International Journal Of Geo-Information	10	118
Automation In Construction	7	132
Sensors	2	56
Ieee Access	2	49
Remote Sensing	1	54
Renewable Energy	1	38
Journal Of Computing In Civil Engineering	1	29
Cities	1	25
IEEE Internet Of Things Journal	1	24

4.4. Co-authorship networks

The co-authorship networks analysis allows the collaboration of authors in related researches topics to be examined, and understand the contribution of each author in the field, comparing the year of publication, the number of papers and their citations. Therefore, contributes to answering the question RQ-3. The total number of authors is 174; however, most of them published a small number of papers and have a small number of citations. Authors with 2 and more articles related to BIM, GIS and Web integration were selected to get clear and accurate results about authors making the greatest contribution to the research field in the analyzed period. In total, 17 authors meet this criterion. Fig. 5 represents the network of authors.

From Fig. 5 it can be seen that Blaschke et al. [77], and Delgado, Martinez-Gonzalez and Finat [78] were among the earliest researchers who investigated the integration of the BIM, GIS and Web environments at the beginning of 2011. Blaschke and Resch [77] published a study in 2011 in which they reported the different types of technologies and techniques of remote sensors for the urban situation, including GIS implementation. This research is not strictly related to Web technologies development, but uses them for data transfer; therefore, such articles are necessary in discussing and proposing solutions for smart city and sensors systems development, which is one of the ways in which information can be gathered for use in Web-based projects. Delgado, Martinez-Gonzalez and Finat [78] presented an article in 2013 in which they started their research about the representation of BIM model

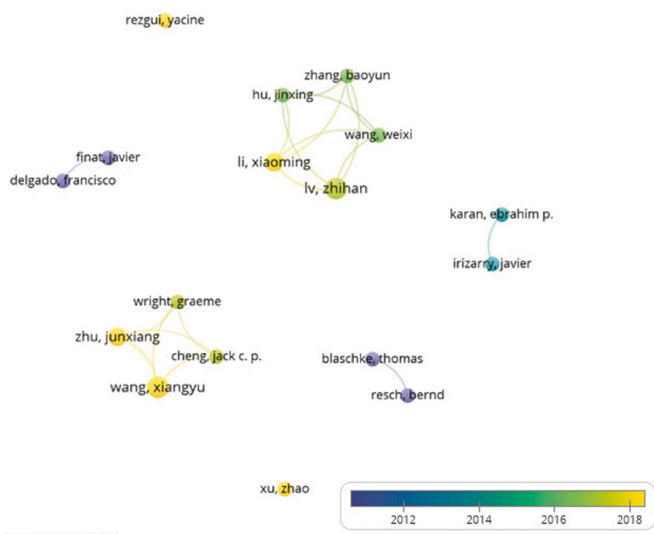

Fig. 5. Co-authorship network of the most active authors with 2 and more articles.

information on the Internet, and after two years published the paper [79] with their results presenting a developed Web3D platform that allows visualization of BIM models in web browsers based on WebGL technology. These kinds of approaches reveal the main obstacles and challenges in the integration process, specifically, the lack of technological solutions and methods.

Table 5 presents the most active authors with more than 2 articles and more than 50 citations. The authors are sorted by the number of their publications and citations.

This analysis revealed that Lv Zhihan has the highest contribution in BIM, GIS and Web environments integration, with four papers and 93 citations. These papers focused on the virtual reality experience in a GIS environment using the Internet of Things. The author connected 3D building models with the IoT and GIS environments based on Web technologies [80,81] and developed a platform for managing city industries, such as transportation, the management of urban resources, and environmental protection [82].

The storage and management of the GIS and BIM data within the Web environment are interoperability issues that authors raise in their articles [47,54,83]. The problem is that the management process has different standards and technological solutions for managing attributive information in each environment. The investigations by Lv Zhihan and Li Xiaoming [83] resulted in the last document published in 2020, which proposes a solution for BIM big-data storage and management based on a web platform in the conditions of a GIS environment. Liu Xin, and Wang Xiangyu and co-authors presented two articles [60] [84] with research about methods and technological solutions for integrating GIS and BIM, including standards for information sharing. Karan and

Table 5
The most active authors in BIM, GIS and Web environments integration.

Author	Documents	Citations
Lv Zh.	4	93
Wang X.	4	74
Li X.	3	68
Blaschke Th.	2	86
Resch B.	2	86
Irizarry J.	2	78
Karan E.	2	78
Hu J.	2	66
Wang W.	2	66
Zhang B.	2	66
Wright G.	2	65

Irizarry [56,85,86] are focusing their research on solving issues related to BIM and GIS interoperability based on semantic web technology for monitoring supply chain management.

In this step, the collaboration of authors was analyzed, intending to detect the largest clusters of research networks in the analyzed field. After applying VOSviewer algorithms, the groups of related authors are generated based on citations. The resultant clusters were depicted in a time scale, which allows the earliest and the latest active members in the clusters to be dermined. The result of this analysis is presented in Fig. 6.

From Fig. 6 it can be seen that Resch and Blaschke were among the earliest researchers who focused on the topic of GIS, BIM, and Web environments integration and have a high number of citations. However, the citation network involves a smaller number of participants compared to other clusters. On the other hand, Lv Zhihan and Wang Xiangyu have much bigger citation networks, even though they only started their investigations in 2017. Such a situation can be explained as follows. When technological advancements reach a suitable level and interest in the field increases, the number of studies increases as well, and each researcher needs to provide relevant and up-to-date article. The latest active researchers presented in the figure as yellow dots more frequently collect information from newer sources and rarely from older papers. Notably, some scientific papers are not connected to any early references that investigated the integration of the BIM, GIS, and Web environments. Such behavior can cast doubt on the comprehensiveness of the previous studies presented in these articles; on the other hand, such research can be outstanding and innovative. The existence of separate, unlinked clusters shows that some authors are working on BIM, GIS, and Web integration in isolated groups. The last observation indicates the need for the mutual exchange of initiatives and ideas in the analyzed field.

4.5. *Analysis of keywords occurrence*

The analysis of the most frequently occurring keywords was carried out to determine the main focuses of investigations in papers related to BIM, GIS, and Web integration. This analysis helps answer the research question RQ-4 (What are the most pressing issues and use cases analyzed in the recent studies related to BIM, GIS and Web integration?).

This analysis is based on the number of occurrences of the item (keyword) in the papers and allows a network of the most frequently occurring keywords to be built. The co-occurrence analysis is useful to convey the main content of articles and the range of investigated areas in a field; it also provides a picture of a field and trends of development in the research area. This type of analysis is notable in bibliometric studies, is based on the results of the existing situation, and allows the current scope of interests to be determined. To perform a comprehensive analysis, all keywords were divided into groups based on their meaning and relevant articles. This analysis was performed based on the data presented in related clusters generated by VOSviewer. The results of this analysis show that the keywords “management” and “analysis” occur most often; therefore, it is necessary to inspect the related keywords to understand the main focuses. Table 6 represents the “analysis” and “management” categories and includes related keywords. The keywords related to the articles published in 2019–2020 are presented in Italic type.

As can be seen from Table 6, in the group of “analysis” the following keywords are in the field of interest: “air-pollution”, “energy simulation”, and “geospatial analysis”. Other keywords in this group are related to the period before 2019: “visibility analysis”, “safety analysis”, “flooding analysis”, “performance simulation”, and “public transportation”. This list of keywords represents the main use cases of BIM, GIS and Web integration in the construction sector.

As can be seen, many articles highlighted the importance of different types of analysis. Some authors propose to use the Web environment to manage the planning process during the design and preconstruction stages [85], others for transportation purposes [87], but most of the

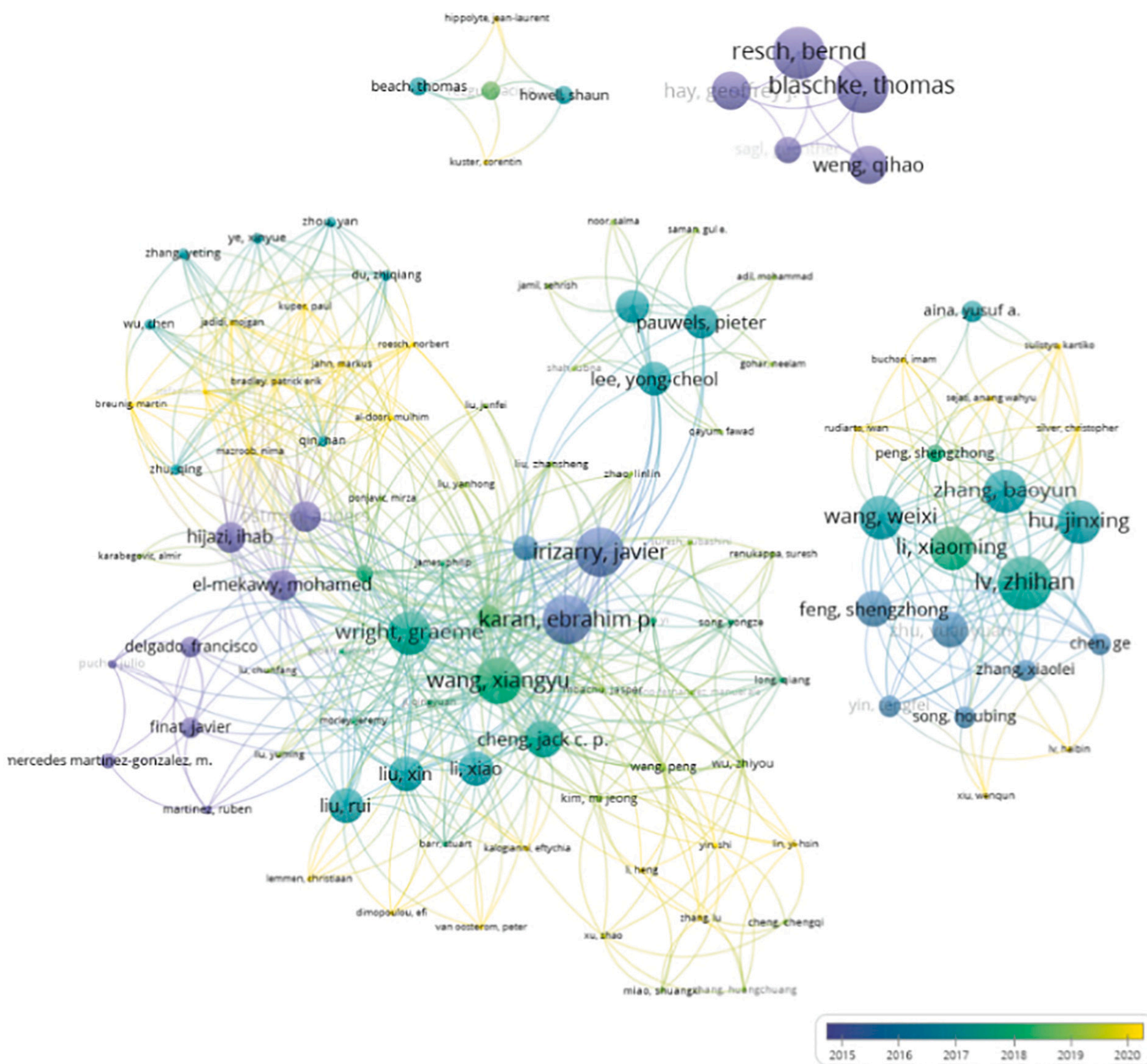

Fig. 6. Citation network of authors.

researchers are focused on GIS analysis implementation [11]. Mao, Ban and Laumert [12] presented a practical implementation of the GIS and Web environments integration. Based on the Cesium framework, the authors developed a web-based system, the main aim of which is energy simulation visualization. Moreover, the visualization of the results is done in real time and based on a sensor network. The proposed approach increases the performance of the GIS map with the help of 3D tiles technology. The authors did not use BIM models focused on city analysis, but they pointed out that the use of the BIM environment will increase the quality of simulation, and the results will be more accurate. This observation highlights the need for GIS and BIM integration. Auer and Zipf [88] presented an overview of GIS analysis "line-of-sight" [89]. This is one of the principal analyses used in GIS because many other analyses are based on it, like military analysis [90], or visibility analysis [91]. The authors reported the usefulness of WebGL technologies to implement analysis, including server-side processing. Such a stack of technologies is sufficient to perform an analysis employing a server-side or client-side solution. However, the authors do not provide any code for any of their solutions, nor any graphical representation of the result, so the results of the article cannot be considered exhaustive. Nonetheless, such research makes an important contribution to the implementation of GIS analysis within the Web environment. Zhang et al. [92] proposed a new approach for combining BIM and GIS for hydropower projects Web visualization based on an IFC file type and highlighted the lack of IFC standards, which leads to losses or changes in information when performing the model exchange and sharing. The most important part of their article is the conversion of coordinate systems that they present. The merging of the coordinate systems is one of the main obstacles in BIM, GIS and Web environments interoperability, but has not been sufficiently investigated yet. The main issue is that the BIM, GIS, and Web environments have individual coordinate systems or even several of them. In the case of environmental coordinate systems conversion, geodesic conversion based on a matrix and formulas can be used, but in the case of local coordinate systems conversion, a linking logic need to be created. Such logic allows the interconnection of local and environmental coordinates, with the possibility of ensuring the response when the change is made. Another important investigation presented in the case study is related to the analysis. The presented analyses include surface contour creation, buffer analysis, networking and safety analysis. All of the analyses were presented from the GIS environment. Last but not least, a point that the authors mentioned is that there are no appropriate widely used standards for BIM, GIS and Web integration [19]. The categorizations method for BIM and GIS integration into Web environment was used by other authors [59,93,94]. In their solutions, the conversion of the IFC model into a Web supportable format is done by using BIMserver [95], which parses the graphical and attributive

Table 6
Main groups of the keywords: analysis and management categories.

Analysis	
Keyword	Occurrence
Analysis	*6*
Geospatial analysis	4
Public transportation	2
Air pollution	*1*
Energy simulation	*1*
Geographical analysis	*1*
Performance simulation	1
Visibility analysis	1
Safety analysis	1
3D analysis	1
Flooding analysis	1
Accessibility analysis	1

Management	
Keyword	Occurrence
Management	3
Management system	1
Urban component management	1
Facility maintenance	1
Facility management	1
Geo-data management	1
Construction management	1
Healthcare management	1
Management strategies	1

information of the IFC file and returns the information as geometry primitives, and as the GIS information provider Google maps were used. Lastly, the GIS environment enables many types of analyses to be performed, and most of the researchers highlight this in their articles. However, not many scientists are trying to develop projects with the practical implementation of analysis in a Web environment, which is a big gap in the integration of the BIM, GIS and Web environments.

Another important field of investigation that researchers are working on is management, as 32 articles contain management-related keywords. The principal use cases related to management are as follows: facility management [61], building management based on a sensor system [96], web-based bridge management system [97], railway engineering [98], and airport management [99]. Separately mentioned should be approaches that propose new ways of data management [100,101]. Zhiliang et al. [102], with the link to Ma and Ren's paper [69], stated that the integration of BIM and GIS was never used in facilities maintenance, as the facility management was focused on risk management and energy management; therefore, the authors decided to fill this gap. They used decision-making models including Reliability Centered Maintenance, BIM and GIS technologies to use a data-driven approach for equipment maintenance. In this research, the GIS information goes from an ESRI shape file; however, the authors used tools to convert this file type to GeoJSON to store the static data of equipment systems and underground pipelines in the object structure of JSON format, which is JavaScript Object Notation [103]. Information for BIM models is presented as IFC files provided by the open-source converter Xbim [104]. To visualize the information from the BIM and GIS environments in the Web environment the stack of Xbim tools and the Cesium [105] library are used. The article concludes that integration of the BIM, GIS and Web environments allows labor costs and difficulties with equipment maintenance to be reduced. In the described case study, the maintenance process took two days of an administrator's work and 35 min of a system to finish analysis. Moreover, Ma [69] proposed to integrate the Internet of Things to support more efficient decision making; however, such an approach was not presented.

Based on the above discussion, the following observations are made. The main groups of the keywords "management" and "analysis" represent the main focuses in the field of BIM, GIS and Web integration. However, from the discussion of the scientific articles, it is clear that each of these groups faces many obstacles at the development and realisation stage, conditioned by the lack of methods, technologies and standards for interoperability of BIM and GIS within the Web environment [18,86,106]. A group of keywords related to technological solutions can be distinguished as follows: "big-data", "3D tiles", "internet", "artificial intelligence", "IFC", "IFC implementation", "cesium", "3D WEB GIS", "geometry", "optimization", "real-time", "smart devices", "standardization", "BIM-GIS integration", "data integration", "distributed databases", "implementation", "informatization", "xml", "CityGML", "NoSQL databases", "open-source software", "data visualization", "maintenance", "monitoring". This group is much larger and reveals the main focuses of research. The most frequently occurring keywords indicate the main obstacles to interoperability discussed in related papers, such as difficulties in data exchange and data storage, as well as a lack of standards and performance optimization issues.

4.6. *Gaps and future areas of research*

An analysis of the propagation of the most frequently occurring keywords in a time scale was carried out to answer the research question RQ-5 (What is the direction of further development in BIM, GIS and Web integration?). This type of analysis helps to predict future research areas in the analyzed field. Such prediction is important because based on it the gaps and the future vector of investigations can be defined in the fields where the number of documents is low or research is not presented at all. The keywords that appeared in research papers between 2019 and 2020 have been collected and analyzed to determine the latest trends, describe the actual focuses and define the vector of further development in the research field. Fig. 7 presents these keywords.

Toshi, Nocerino and Remondino [107] pointed out that in 2017 the models on the building level were mostly used for visualization purposes and rarely with other aims such as cadaster, real tile monitoring of the various fields, and analysis. However, this situation is changing every year with a growing number of research papers. The in-depth analysis based on the keywords depicted in Fig. 7 is presented in the paragraphs below. The important keywords in the discussion below are determined by the strength of their link with each environment.

The most frequently occurring keywords with strong links to GIS in the period from 2019 to 2020 are "BIM", "smart city", "management", "big data", "semantic web", "design", "model", "support", "interoperability", "urban component management", "challenges", "integration", "strategic management", "built heritage", "intelligent construction", and "AEC sector".

From this it can be concluded, that one of the focuses that researchers are working on is BIM and GIS integration with Web environment in the fields of urban planning and management. It should be highlighted, that the list of keywords related to integration issues has strong links, such as "support", "interoperability", "integration", and "challenges". On the other hand, GIS does not have strong connections with the Web environment. Such results allow the conclusion that the focus of researchers working in the GIS environment is mainly on solving GIS and BIM integration issues and not on GIS and Web interaction. This situation appears because GIS and Web integration attracted more researches at an earlier stage, which results in a fewer gaps in comparison to GIS and BIM integration, which can be seen also in Fig. 2.

The most frequently occurring keywords with strong links to BIM in the period from 2019 to 2020 are "GIS", "management", "support", "design", "semantic web", "GIS-BIM", "interoperability", "expansion", "big data", "integration", "smart city", "data model", "3D tiles", "visualization", "Internet of Things", "internet", "cloud computing", "web-gis", "development stage", "decision making", "healthcare management", and "air pollution".

Such links between keywords allow the conclusion that authors are focusing on solving the problems related to the integration process, such as performance issues, data transfer, and analysis. Additionally, based

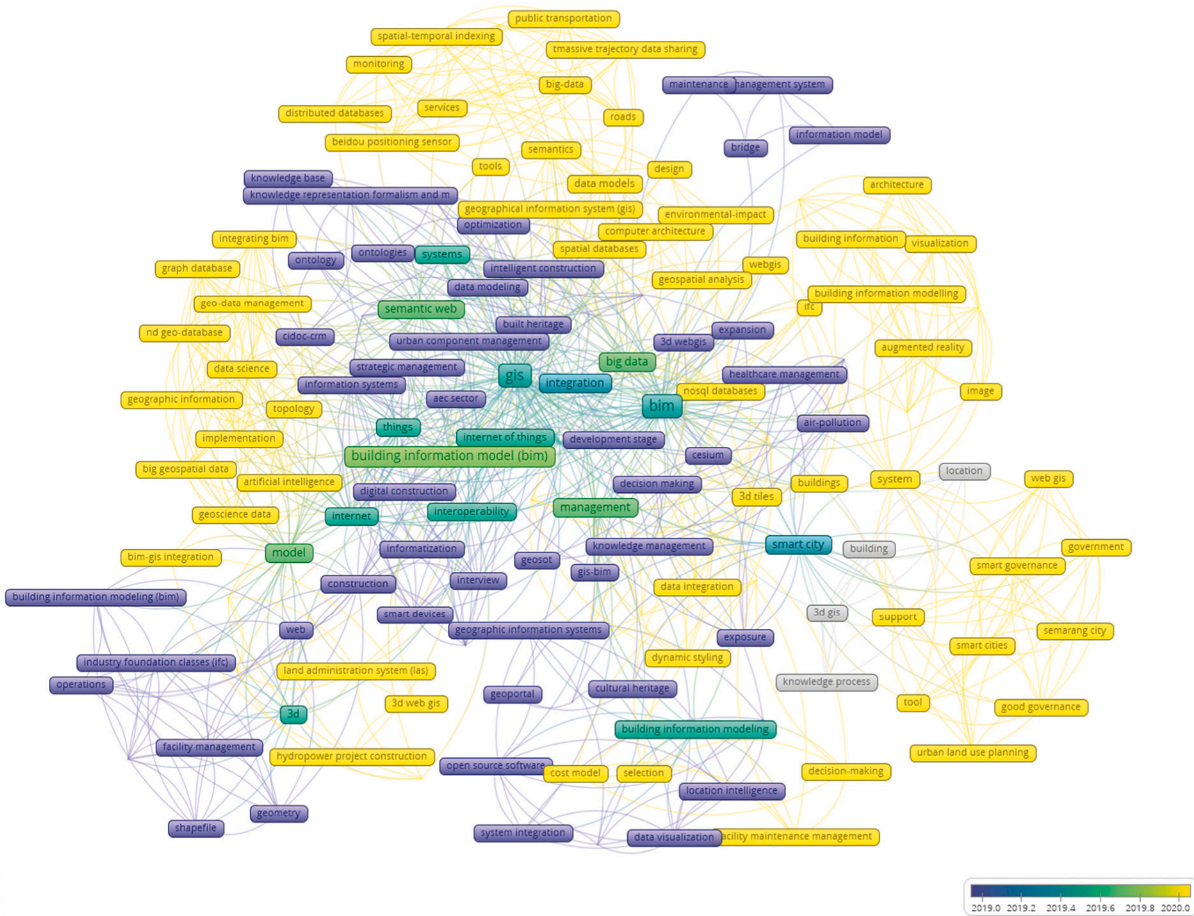

Fig. 7. Co-occurrence map of keywords in 2019–2020.

on the keywords above, BIM and GIS integration has much stronger links compared to BIM and Web integration, which repeats the situation revealed in the analysis of GIS-related keywords. This situation can be explained by the low number of articles on BIM and GIS integration compared to BIM and Web integration. The list of keywords related to the integration obstacles is similar to those on the GIS environment; however, BIM and Web integration has stronger links compared to GIS and Web integration. From Fig. 2 it can be seen that the number of articles related to BIM and Web integration is aroung half the number of GIS and Web research works.

The most frequently occurring keywords with strong links to the Web in the period from 2019 to 2020 are "BIM", "GIS", "semantic web", "construction", "design", "IoT", "visualization", "model", "facility management", "big data", "energy", and "system". The integration of the Web environment with BIM and GIS has already benn addressed in the discussion presented above. An additional investigation of keyword chains has been performed to provide a fuller picture of this integration. The idea is to inspect the chain of the keywords that form the bridge that connects the above-highlighted environments, and the following keywords were determined: "semantic web", "big data", "design", "IoT", "visualization", "support", "framework", "smart city", "integration", "technology", and "interoperability". These keywords prove once again, that the central area of investigations related to BIM, GIS, and Web integration is BIM and GIS interoperability, while the second area of investigations is BIM and Web interoperability. The main points in the research are data transfer and processing, management, visualization methods, and framework development. The main focus is on interoperability and the support challenges, methods, and technological solutions of the integration process, including smart city, IoT, semantic web, and big data.

This analysis reveals that the evolving trend in developments related to BIM, GIS, and the Web started with concepts like parametric design, visualization, and various types of analyses, followed by a focus on the interoperability of all three environments, and shifted towards recent ideas of big data analyses, IoT, cloud computing, decision-making, and smart city. The specific technical capabilities of BIM, GIS, and Web interoperability are still in their infancy. This shows that the body of knowledge can be expanded, and future research in the field of BIM, GIS, and Web integration should, first of all, be focused on solving the interoperability challenges, including standardization, BIM model processing, data exchange and storage, and performance optimization. When the main interoperability issues are solved, the development should switch to the practical implementation, specifically, management, analyses, IoT, smart city, and semantic web.

5. Conclusions

This study is the first to use bibliometric analysis to examine the state of published scientific papers linking BIM to the GIS and Web environments. Bibliometric analysis of the literature is one of the most effective methods to determine the existing situation of researches in the field of interest without the author's subjective judgments.

The analysis of the current situation revealed that the number of scientific research works on BIM, GIS, and Web integration is not sufficient to solve all the problems of the integration process. A small amount of scientific research cannot cover all the gaps in the research field. That should be considered as proof of the need for further investigations.

Based on the results of the research trend, it can be concluded that the number of scientific papers grew in the last decade and reached 52 articles, which reflects the growing interest in BIM, GIS and Web integration. Some research efforts in the form of literature reviews are available on related fields like BIM and GIS integration, and some of these reviews are related only to BIM technologies. The existing studies can not be considered exhaustive because they do not provide complex information about the integration of all three environments (BIM, GIS, Web). This study stands out from other similar ones because it offers a picture of the body of knowledge concerning BIM, GIS, and Web integration, as an area that remains unassessed.

The study contributes to the field by raising awareness about the problems of BIM, GIS, and Web integration, and by providing original insights into the issues related to technical aspects of the integration process. The study also indicates the problems of BIM, GIS, and Web integration that have been investigated and what remains to be examined. Methodologically, the observations of the study are based on a quantitative analysis of citation networks, which suggests minimum subjectivity, making the conclusions credible and consistent. The findings presented reveal that research on BIM, GIS, and Web integration is still in its infancy, with many gaps; nevertheless, the subject has attracted much attention and has a promising future.

The analysis of the citation network of authors revealed that the development of the above-highlighted integration involves countries and organizations from various regions.

Co-authorship network analysis and citation network analysis determined the researchers making the biggest contribution to the integration of the BIM, GIS and Web environments. Even though many authors are investigating problems in the field of BIM and GIS integration, the research work in this area has been conducted mainly in isolation, comprising disjointed and fragmented research studies. The formation of research networks of cooperation is needed for extending further research. Intensive dialogue, debates and mutual exchange of initiatives and ideas will be a priority.

Based on the results of keywords analysis it can be concluded that the main investigation field of the research is related to the BIM and GIS interoperability challenges. Mainly, researchers are investigating methods and technological solutions to the integration process, interoperability, and support challenges. The principal use cases that researchers are investigating are analysis and management. Mostly, the analysis field consists of GIS analyses that mainly focus on environmental analysis, which is usually used within the GIS environment. Such types of analyses use various inputs to receive and process data, such as the BIM model, remote sensors, IoT, and databases. On the other hand, management starts from the BIM model and project management and continues with all kinds of data management. These two fields are the main focuses that researchers are working on today. However, in BIM, GIS and Web integration, many obstacles and problems exist, the most important of which are explained below.

Many authors pointed out that there is a lack of technologies and methods for BIM and GIS integration within the Web environment. This obstacle exists because Web technology does not have default tools and methods for BIM model processing; moreover, most construction software tools use proprietary file formats that cannot be processed outside of proprietary software. Such file types present significant obstacles to interoperability because they need to be converted into web supportable file formats, which leads to information transformation and loss. Each team of developers faces this problem, although open-source projects are trying to solve it.

Another problem is that no unified standards can be applied. As every environment has specific standards and methodologies, researchers are trying to use them in the integration process and develop new file types. At the moment, a lack of unified standards is one of the main obstacles that needs to be investigated, because their development will extend the opportunities for BIM, GIS and Web environments interoperability. Separately, it should be pointed out that it is necessary to develop such standards for the integration process, including BIM models integration, information sharing and storage, information processing and much more.

Another gap in the BIM, GIS and Web integration process is related to a lack of basic technical solutions presented within the construction model, for example, the relations of the objects inside the BIM model. Such basic techniques are as important as standards; however, they have still not been developed and implemented within the Web environment. It would be correct to point out that such developments should be carried out with the same priority as others.

The timescale analysis of keywords occurrence reveals that the further vector of research in the field of BIM, GIS, and Web integration should be related to interoperability solutions, including standardization, BIM model processing, data exchange and storage, and performance optimization. Thereafter, the developments should switch to the practical implementation of the research, specifically, management, analysis, IoT, smart city, semantic web.

Despite the contributions, this study has limitations. First, the analysis is based on a set of data obtained from the Web of Science database and covered only literature published in English, thus, limiting the coverage of the analysis. The results may therefore not fully reflect all the available publications on BIM, GIS and Web integration. There is a high probability that "stand-alone" projects have been implemented for some time without being published in scientific peer-reviewed journals. This leads to the conclusion that the promoters of projects should be encouraged to publish their research results more actively in scientific journals to raise the visibility of the advancements. Besides, due to limitations of space, this study was focused on providing a broad picture of the available literature on advancements in BIM, GIS and Web integration through a bibliometric analysis and only to a lesser extent related to in-depth analysis of the content of the exting studies. Nonetheless, the authors conducted an in-depth qualitative analysis of the articles discussed in this study.

Data availability

Data generated in this research are available from the corresponding author on request.

Declaration of Competing Interest

None.

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