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Integration of the structural project into the BIM paradigm: A literature review

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ABSTRACT

The revolution towards Industry 4.0 in the AECO Industry has taken Building Information Modelling (BIM) as one of its central points. BIM abilities for automatization, interoperability and sustainability play a key role in this change. In this paper, a literature review about BIM adoption for the structural project is presented. The aim of the presented review is to clearly establish the current state of knowledge of the implementation of the BIM methodology in the field of structural analysis. Papers related to these two topics simultaneously, BIM and structure analysis, during the last 10 years have been selected. The literature has been analysed from two different approaches. First, bibliometric analysis has been performed, studying the production on the topic. Secondly, 81 representative papers have been selected and analysed, establishing thematic areas via cluster analysis. The articles have also been classified upon several categorizations based on the structural life cycle and their aim. Finally, a SWOT analysis is performed from this data to create a complete framework that shows the state of the integration of the structural project in BIM environments and possible future developments and risks. This set of studies shows a tendency towards design tools and new buildings. While automatization and computer-aided design have been a trend in the research for several years, a research gap on the structural analysis via BIM for existing and heritage buildings has been pointed out, showing its ability to improve the analysis of existing buildings and its maintenance.

1. Introduction

Traditionally, the Architecture, Engineering, Construction, and Operation Industry (AECO) is a slow shifting business not subjected to great changes. However, in the last years, several technologies and procedures have appeared and they are making it a change adopting Industry 4.0 standards of digitalization. The fourth industrial revolution is generally associated with the manufacturing sector. Sustainability, automation, risk management, and productivity are a few of the demands for a competitive business nowadays. The AECO needs to evolve to incorporate them and improve its competitiveness towards the digital revolution. Some techniques like Life Cycle Analysis are being studied and developed to take into account new parameters and use them as a central point for the design [45,79,82]. There are also other new parameters being studied such as the social sustainability of the project based on the impact that it has on the society taking into account the interaction of the infrastructure with its environment [91].

Among these new methods, Building Information Modelling (BIM) [20,57] and Virtual, Digital and Hybrid Twins [30] are a link from digital technologies to the AECO Industry and main forces of this change. They allow the professional to face these new challenges

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and deal with problems that affect the industry. In addition, it makes it easier to control every dimension of the project. It also provides a common workplace through cloud technologies by reducing coordination issues and errors. BIM environments have brought new functionalities and new perspectives [19,50] and they are creating a digital transformation in the sector [58].

Due to BIM creating an n-Dimensional model, it is an ideal tool to add new layers of development to the building project and to integrate the new demands onto it. The capabilities with BIM are quite large [25] and there have been studies developing different areas around them. Our main focus is going to be the structural project and how its integration into BIM can improve it. The new assets provided by BIM open a new world of possibilities, from taking into account sustainability parameters during the design phase [34,41,74], to risk management during the construction phase [104] and using optimization algorithms to reduce the costs [43] and also to take advantage of the demolition waste to build new projects [6]. A review of different articles approaching the advantages, disadvantages, and risks of using BIM to develop the structural project is necessary to understand what has been studied and what needs further research, also to point new paths to follow in the near future.

Building Information capabilities are so widespread that despite it has received a lot of attention for more than ten years now, there is not a consensus for a definition. BIM understanding varies depending on how professionals use and see it. Ontologically it can be understood as one or more than these three things, a methodology, a product, or a method. Based on this approach and also the definitions [37,105] a BIM definition has been put together. BIM is a technology related to the AECO based on the production of three-dimensional parametrical models of the project, but it is more than the production of the digital models. In addition, these models must have the capacity to communicate, modify and analyse themselves. Everything in the model is updated in real-time and uses parameters linked among the elements to share their properties. Thus, BIM technology has allowed us to create an n-dimensional model of a project that can be modified at any dimension at any time while keeping the parameters linked and updated.

In the coming years, BIM is going to be an essential skill to be competitive in the AECO Industry and it is going to be mandatory for the members in the industry [14]. Universities will need to implement BIM into their curriculum or it will become a training gap for young engineers and it will affect their employability [95]. The study programs need to evolve and incorporate management and administration into their competencies to be on par with what employees seek [102]. The incorporation of BIM into the engineering programs will create professionals with the required skills for the new challenges that the Industry is facing. This progressive incorporation has to be done in several steps or layers, implementing different technologies along BIM to achieve a Construction 4.0 Industry [39].

Companies are pushing to be more and more competitive and are investing in innovation [78]. The relevance of BIM is not restricted to academic work, as it has direct professional applications. There are a lot of different reasons for a corporation to start using BIM, for example, it can create a 10% cost saving and a 7% flat time reduction [13]. Despite other benefits harder to quantify like the reduction of errors, reduction of 40% time in unbudgeted changes, higher accuracy, and easiness to get a cost estimation. AECO companies are demanding BIM knowledge more and more as a requirement for hiring new employers.

There has also been interest in the standardization of BIM from different governments throughout the globe. The European Union established back in 2014 the directive 2014/24/EU with the objective of implanting BIM in Europe in 2021. This has led, to several countries setting goals for BIM adoption. The UK fully adopted the BIM methodology in 2018 [28] and Spain is following a route to fully implement it in 2020 [61]. The other European countries are also working on the creation of strategies and resources to take benefit from BIM. Outside of Europe, there has also been governmental interest. Malaysian started to demand its use in 2016 and from 2020 it has been mandatory [72]. To be able to fulfil this objective, some international organisms have been founded like BuildingSMART, which operates in several countries analyses the state of BIM and proposes ways to rightfully implant it.

Standardization is key for BIM environments and to grant its interoperability across different professionals, tools and analysis. Some institutions like the International Standardization Organization (ISO) are trying to create regulations to standardize the BIM Methodology with regulations as the ISO 19650.

1.1. Research questions

The main purpose of the study is to specifically determine the level of development of the structural project on BIM and what has been achieved nowadays via a state-of-art approach. There is also the need to determine the actual trends and obstacles to get full integration of the structural project and study the advantages obtained from it at the moment and the points in need of further research. The main questions to answer in this paper are:

- What is the level of development of the structural project on BIM environments?
- Which are the current thematic areas and research trends on the topic?
- How BIM environments have contributed to the structural project and how can this be further improved?

To answer these questions the bibliography and the trends and strengths of the researches developed nowadays for this purpose are reviewed and studied. Thanks to this analysis a framework can be created where the whole structural-BIM picture is exposed with a comprehensive approach. By performing this research, the research gaps on the field are going to be established and in consequence future research lines will be determined.

Using this framework, the state-of-art of structure project in BIM can be established and a “Strengths, Weaknesses, Opportunities and Threats” analysis will be carried out, determining its trends and risks. Also, different deficiencies in the current research lines, the research gaps or main topics are found. This will show new areas to research and expand the BIM capabilities.

2. Methodology

BIM has been widely adopted in the AECO Industry and it has proven more than capable to administrate the projects and granting some advantages to them during the whole project's life-cycle. In this paper, a full field view on the adoption of BIM for the structural project is presented, understanding it as continuous during the structure's life cycle. It is intended to study the actual development of the structural project in the BIM methodology and further understanding future trends, research gaps, and expectations. A systematic, objective review is done to seek the progress achieved and the weak points that need more focus. To accomplish this a five-stage structure has been adopted [32]. The first stage is the formulation of the problem and has been performed in the previous section. The second stage deals with the determination of the data collection strategy, the third stage revolves around evaluating the retrieved data, the fourth stage points to the analysis and interpretation of the literature and finally, the fifth stage presents the resulting questions.

2.1. Data collection strategy

The data collection is based upon a search performed using the internationally-recognized bibliographic database SCOPUS. This database was chosen due to its depth in coverage and its ability to filter the results by year and search forward and backward from a citation. The SCOPUS database was the main one used, but later on, complementary databases such us Web of Science, ScienceDirect or Google Academics were also reviewed to be sure to get the whole picture. To have a general view of the research effort regarding BIM and the structural project two search algorithms have been used. The first search algorithm was conducted on the SCOPUS database using the keyword BIM to have a general idea of the research effort in the field. It gave a result of 10.519 articles. This first search was limited from 2004 onwards as at this year the term BIM gained more attention after the conference "The Great Debate BIM" [62] and can be considered a starting point.

The second search algorithm was conducted to collect any article within the database for this the keywords "BIM" and "structure project" and the Boolean tool "AND" of the search engine were used to get the references that were related to both terms. The time period was limited to the years from 2010 to 2021 to select the latest research possible. This second search resulted in the Raw Set containing a total of 1.905 documents. Fig. 1 shows the query strings used in the databases' search engines; the thematic areas were filtered according to the scope of the research.

2.2. Filtering and expansion processes

After having collected the data, a filter was applied to select the most fitting researches among all the results. The first step to this filter was to exclude those articles with keywords unrelated to the topic (with terms related to air ventilation or medicine for example). A final filter was applied to erase those articles that despite being associated with the research were deemed to not be part of the core of it, this was done by reading through the different articles' main body. From there, an initial corpus of 60 articles was selected to complete the analysis and determine the state of art.

To finish this initial corpus and improve the dataset we have included 21 more articles, creating the Expanded Set with a total of 81 papers. These documents were added after performing a review of the references among the initial corpus and with previous knowledge from the research groups. The new papers have been added as they have been considered basic for the complete understanding of the field as they have been used as references on several kinds of research. Some of these papers are outside the time gap considered in the beginning but are still being used due to their importance. To have a more widespread thematic selection, it has been avoided to select more than one articles per author so different research groups can be taken into account. The selected articles are shown in the bibliography and the selection process is summarized in Fig. 2.

2.3. Evaluation of the data

The database is going to be used to perform two sets of analyses. First, an informetric approach that will take into account all of BIM published research, using the Raw Set. Second, a qualitative approach, using the Expanded Set and based on its content, trends, and intentions. Fig. 3 contains a flowchart with the different steps followed during the research.

The first analysis is used to study the evolution of BIM interest through the number of articles and to create a time-based overview

a) TITLE-ABS-KEY**(BIM) AND** PUBYEAR **> 2003 AND** PUBYEAR **< 2022 AND (** LIMIT-TO **(DOCTYPE,"ar")** OR LIMIT-TO **(DOCTYPE,"cp")** OR LIMIT-TO **(DOCTYPE,"re")) AND (** LIMIT-TO **(SUBJAREA,"ENGI") OR** LIMIT-TO **(SUBJAREA,"COMP") OR** LIMIT-TO **(SUBJAREA,"MATE"))**

b) TITLE-ABS-KEY**(BIM) AND** TITLE-ABS-KEY**(STRUCTURE PROJECT)** PUBYEAR **> 2003 AND** PUBYEAR **< 2022 AND (** LIMIT-TO **(DOCTYPE,"ar") OR** LIMIT-TO **(DOCTYPE,"cp") OR** LIMIT-TO **(DOCTYPE,"re")) AND (** LIMIT-TO **(SUBJAREA,"ENGI") OR** LIMIT-TO **(SUBJAREA,"COMP") OR** LIMIT-TO **(SUBJAREA,"MATE"))**

Fig. 1. a) Query string used in the search engine for BIM. b) Query string used in the search engine for BIM and Structure Project.

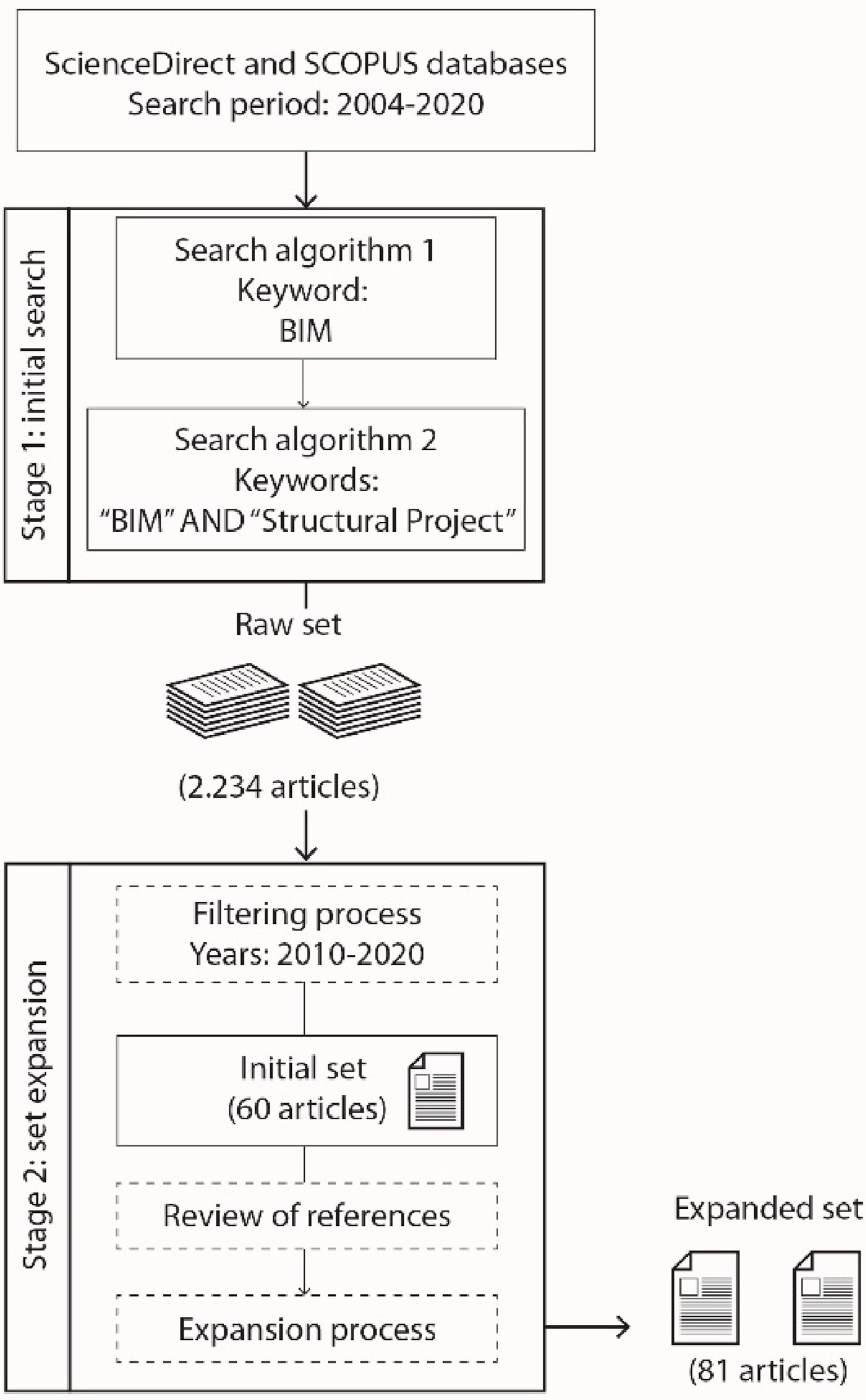

Fig. 2. Data collection strategy.

of the whole framework and its characteristics. The second analysis has a span of time that has been limited from 2008 to 2021 and is used to study the actual trends and development of BIM. The articles in this second span are used to perform the qualitative analysis as they will give information about the research trends nowadays.

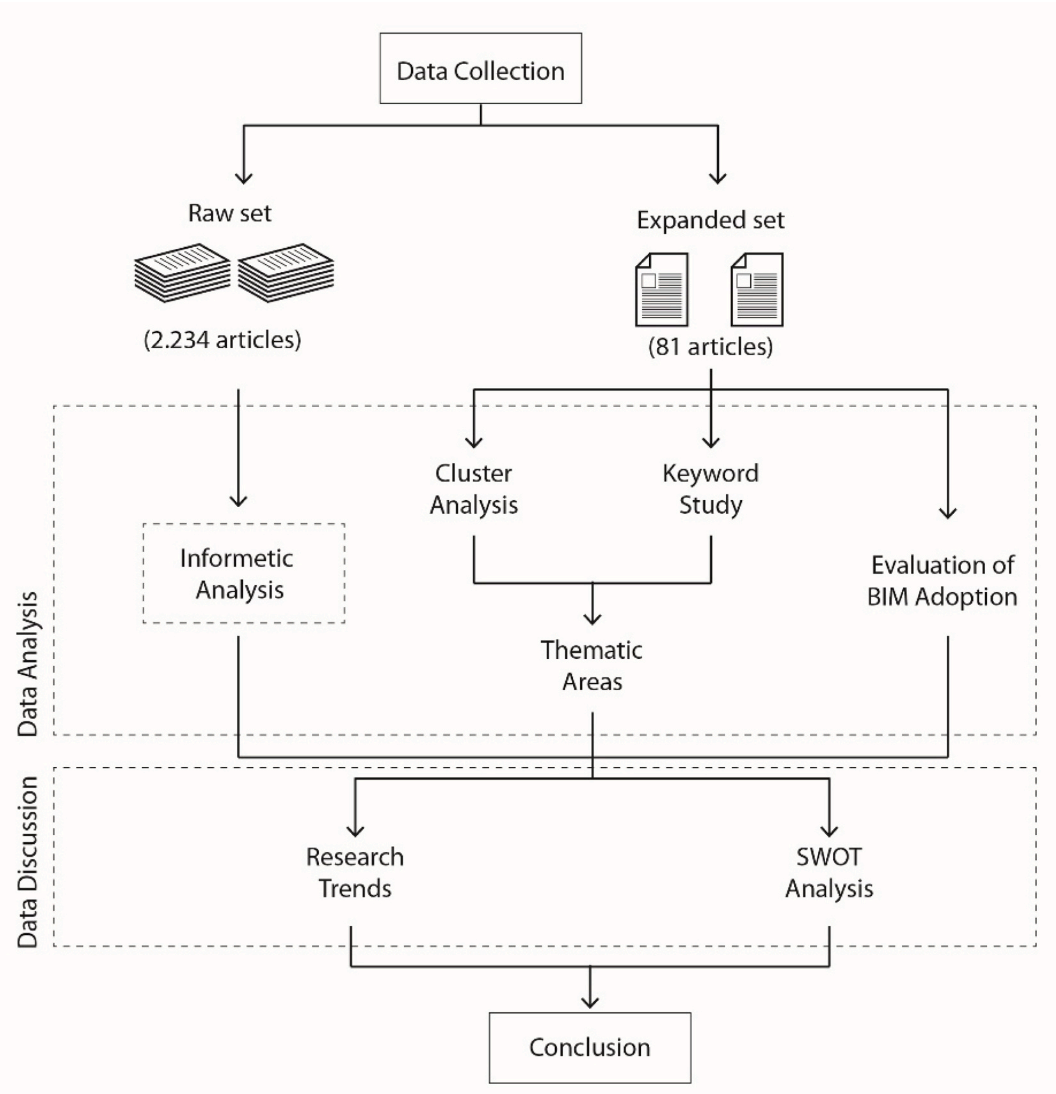

Fig. 3. Flowchart of the performed research.

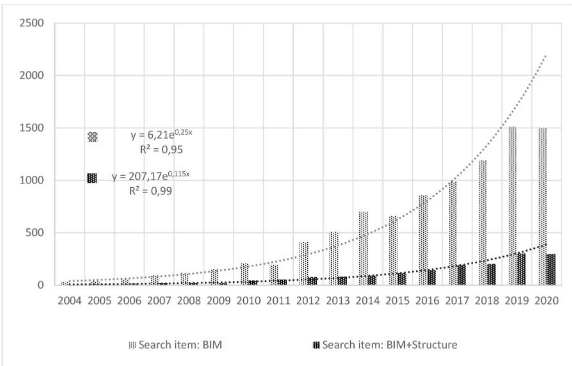

Fig. 4. Number of studies related to BIM per year.

Table 1
Articles published in top 10 journals according to ScienceDirect database (2004–2019).

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total	%
Automation in Construction	1			3	4	6	17	20	22	39	32	40	39	46	74	86	103	532	27%
Procedia Engineering								5		6	7	29	34	61				142	7%
Advanced Engineering Informatics					2	6	5	11	6	8	6	14	8	7	16	11	17	117	6%
Journal of Cleaner Production												4	6	16	11	23	30	90	5%
Energy and Buildings				1						1	9	8	7	13	9	12	7	67	3%
Renewable and Sustainable Energy Reviews										3	3	3	5	9	4	6	5	38	2%
Building and Environment											2		3		5	9	11	30	2%
Journal of Building Engineering																17	17	34	2%
Sustainable Cities and Society										2				4	4	6	12	28	1%
Energy Procedia												3		12				15	1%

Table 2
Articles in top 10 journals and the total number of articles according to ScienceDirect database.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Total of papers included	1	0	0	4	6	12	22	36	28	59	59	101	102	168	123	170	202	1093
Total	10	9	11	18	21	19	37	58	58	89	118	183	184	264	223	305	378	1983
Percentage of publications included	10%	0%	0%	22%	29%	63%	59%	62%	48%	66%	50%	55%	55%	64%	55%	56%	53%	55%
Mean % for each period	12,16%					59,85%						55,57%						

The analysis of the Expanded set is divided into two different studies. By using cluster analysis on the data in the title and abstracts we are able to find the different thematic areas that are being studied and research trends. Later on, by classifying each one of the articles based on the scope and content through the life cycle of the structure. With this pair of analyses, we are able to view the data from the Expanded set from two different points of view and determine precisely the knowledge gap.

After the two datasets have been studied a discussion based on a SWOT-type analysis will be performed, where the state of the art of BIM in the Structural project will be put together highlighting its strong and weak points. The analysis SWOT is used as a strategic approach to evaluate the strengths, weaknesses, opportunities, and threats related to project planning. It has its limitations but it is a solid methodology to set starting points and gather and summarize information in an understandable way. Condensing it into objectives or trends and thus creating a framework where all the aspects are taken into account. This methodology has been used since the 60s in several studies with great results.

3. Results and discussion

3.1. Quantitative analysis

The publication of studies about BIM increased after the year 2007 with an exponential trend [Fig. 4], after this year 98,80% of the publications were made. The year with the highest number of publications so far has been 2020 (1.500 publications for BIM and 297 for BIM and Structure Project), meaning that the interest is still growing and presumably the number of publications will keep increasing as the number of articles published until 2021 December is following the trend of past years with an increasing number of articles published. A total of 10.519 articles have been published during these years regarding BIM and 1.905 regarding BIM and Structural Project, a 18,11% of the total.

The total number of articles related to both BIM and Structural Project is also increasing each year, but the growth rate, even being also exponential, is not as high as the numbers speaking only about BIM. From 2017 onwards there has been a slowdown in the growth rate.

The informetric analysis conducted on journals articles covers the papers published in the top 10 most publishing journals of the topic according to ScienceDirect database and covers a total of 55% of the articles published between 2004 and 2019. As Table 1 summarizes the first published article was published in 2004 in 'Automation in Construction' and there were no more publications until 2007 in these journals. As we have seen in Table 1, there were papers published in those years, but not in the studied journals. With the exception of 2017.

'Automation in Construction' has been the scientific journal that has published more papers with an of 27% of the total production on the topic, followed by 'Procedia Engineering' with 7% of the production and who published a total of 61 papers in 2017 and none since then. The higher number of articles published in a single year has been 2020 with a total of 378 articles, 103 of which were presented in 'Automation in Construction.

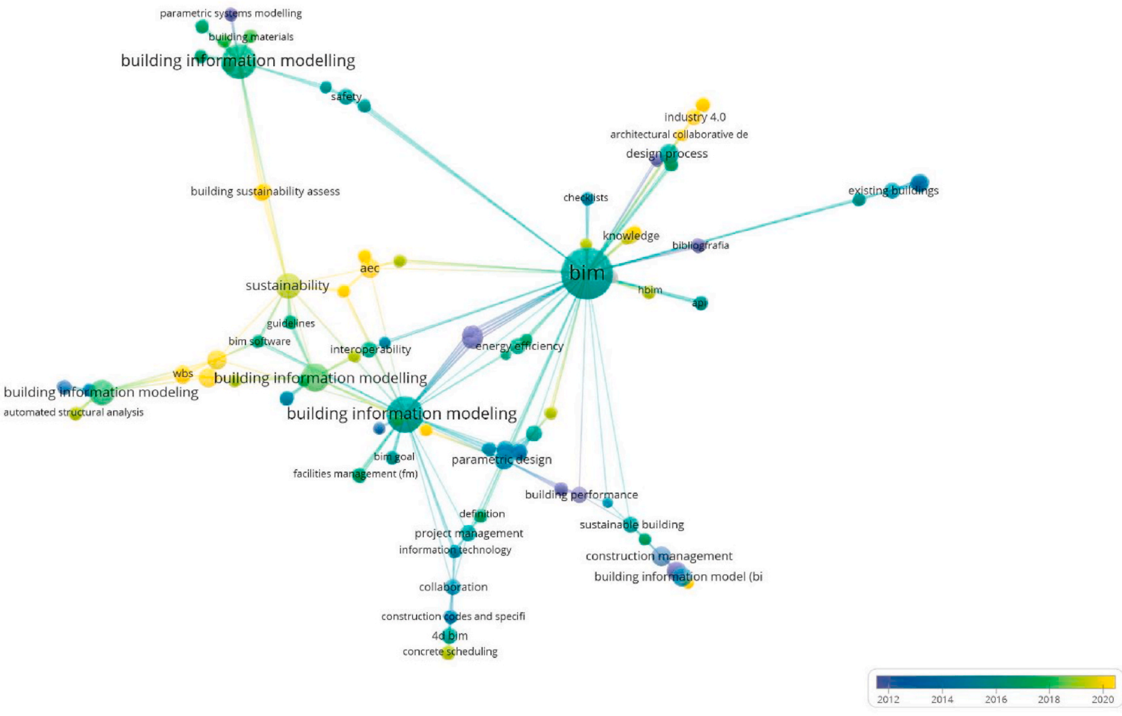

Fig. 5. Cluster analysis.

From 2013 onwards a growth can be observed in the number of journals, such an advance indicates that, although BIM received interest in the early years in some specific journals on the field, other journals have gained interest in the topic as it presented more synergies and a broader view. This is also seen because despite having analysed only, the top 10 journals in the number of publications and 55% of the papers, the journals 'Building and Environment', 'Environment Journal of Building', 'Sustainable Cities and Society' and 'Energy Procedia' have each a 1% of the production published and all of them started publishing about BIM in 2013 or later. There are new journals publishing papers about BIM. 'Journal of Building Engineering' presents the biggest growth in interest in the topic, as from 2019 it has published at least 17 papers per year being the third publishing journal in the last years.

Table 2 shows the spread of publications among different journals by comparing the number of articles included in the top 10 most published journals with the total of articles published. This percentage indicates the fraction of research condensed in these main journals. A higher percentage means that they have published the highest number of papers and concentrated the research efforts. We can divide the studied period of time into three sections. The first period starts in 2004 until 2008 and shows less concentration in the publications, but an increase in it, as it grows from 10% of the articles contained in the journals until 29% of them having been published. In this period the articles were published mainly in two of the top 10 journals 'Automation in Construction' and 'Advanced Engineering Informatics'. This fact is also true during the second period from 2009 until 2013, where these two journals not only are the main publishers of BIM and structures but also capitalize on them most of the research of the topic with 60% of the scientific production. From 2014 the concentration of work in these journals has been reduced to roughly 55% and as we have shown in Table 2 the other top 10 journals have increased their production. This shows an increase in the attention and importance given to the topic.

3.2. Qualitative analysis

Among the studies, we have selected a total of 81 articles that cover the most common thematic areas through BIM researches. This selection forms a sample that shows the different topics about BIM and Structural Project in the last years and its state. With the Expanded Set, we have performed a cluster analysis. The authors performed this analysis using the software VOSViewer, which is often used in bibliometric, informetric, and scientometric studies [38].

The cluster analysis is the first iteration to find the trend in the research and its gaps. It graphically shows the researched topics, density, and connections. To perform the cluster analysis the keywords in the papers conforming to the Expanded Set have been extracted. Inside the VOSviewer software, 311 different keywords were found across the 81 articles. The cluster was set to take into account any keyword with repetition equal to or superior to 1. The resultant cluster analysis is shown in Fig. 5. The keywords with more link strength are the terms *"BIM"* and its derivatives, which are associate with almost every other keyword in the cluster.

The keywords of the articles are an indicator of the topic and the research of the paper, so they are a way to evaluate the focus for each article. In Fig. 5 the keywords from the Expanded Set have been sorted in a total of 5 clusters, regarding different topics. The different clusters comprehend the terms related to them considering their connections and uses. Studying the different clusters in the keywords different thematic areas of research can be defined and group the knowledge for each of the clusters.

This cluster analysis shows the evolution in published topics over the years, the keywords used in more recent publications are related to the term "Sustainability" and "Industry 4.0" which proves what is presented in bibliography research papers [7].Meanwhile the keywords in older papers are more diverse and present different topics. There is also more aggrupation on the left side of the cluster, meaning that the later works revolve around the same topics. As expected, the keyword BIM (and variations such as Building Information Modelling) is the most prevalent one across the years.

There is a total of 5 different thematic areas, that cover the topic of the keywords found in the article. The first is 'BIM' which is only used for this same keyword due to its importance. The second 'Design/Performance' is referred to keywords related in any way to the design procedures and techniques improvement. The area 'Sustainability' includes words with a 'green' meaning that are looking for a reduction in the natural resources invested in the building in any way. The fourth is 'Management' which comprehends the terms that speak about project management and delivery. The last thematic area is 'Life cycle' used for keywords that are referred to the timestamps on a building or its performance during its life cycle.

- BIM is the widest thematic area, as it defines the research field. The keywords closest to the term are included in this area, such as BIM, Building Information Modelling, BIM Use, BIM Goals and HBIM. There are also keywords related to the general description of the field such as Literature Review, AECCO, Industry 4.0 or IFC among others. Across the papers related to this thematic area, we can find several literature reviews with a different approach that cover and look for gaps in the research. Since the release of the BIM Handbook [37], several reviews from different points of view have been done. There are several assessing the BIM development to that point from different points of view, the use of BIM for Green Buildings [66], the adoption for sustainability [31], risk management [104] and the use of Multi-Criteria Decision Making Tools with BIM [94] or reviewing HBIM, BIM applied on Heritage buildings [81].
- Design/Performance keywords are descriptive to new capabilities of BIM to improve the work of the professionals. In this thematic area, there are words such as Building Performance, Parametric Design, Genetic Algorithm, Design Aid, etc. These keywords are used in papers that explore the improvement of the building performance of energy assessment in the early stages of the project [63, 87] or optimize the design for sustainability [64]. There are also papers that present new tools developed to aid in the design through optimization tools as BPOpt [84], create geometrical models for structural analysis [52] or perform structural analysis of curtain walls [75]. Different case studies showing examples of use to get the Green Star Building Certification in Australia [44] and the demolition waste management [51]. The use of BIM in historical buildings has been assessed with approaches to create digital models of existing buildings by using point-cloud techniques [12,54] and with case studies in Seville's Cathedral [10] or modelling the building's decay of Palazzo Sarmatoris and Smistamento Round House in Italy [29]. After creating the digital models for

existing buildings there are studies which implement analysis upon the model to monitor the health of the Flaminio Stadium in Rome [33], conservation state of Dublin's Four Courts [36], refurbishment of a traditional building in Oporto [85] or earthquake damage [16] or structural analysis [12]. To achieve the structural analysis from a scan-to-BIM 3D point cloud a pipeline has been proposed [80]. The difficulties to use BIM in different decision-making processes have also been discussed by several researchers [42,76,77].

- Sustainability terms relate to the new trends in the AECO Industry regarding it and BIM. This thematic area includes keywords such as Sustainable Development, Environmental Impact, Green Buildings, and Energy Efficiency among others. There are several researches driven to integrate BIM and Sustainability [7]. These keywords are used in researches looking to reduce the embodied energy in construction [15,89]. The capabilities of BIM can be used to improve the energy efficiency in buildings in different ways [40,50] or to support performance-oriented sustainability design [46]. The LEED standard is gaining relevance in the AECO business and can be used with BIM [99]. It is also relevant the research in Ref. [2] about sustainable development through improvement in the facilities of the buildings and its different approaches in different countries. How to use BIM to contribute to the Building Sustainability Assessment by using the software SBTool is presented theoretically [21] and with a case study [22]. A parametric LCA BIM tool, focusing on both operational and embodied energy perspectives has also been presented [9].
- Life Cycle is the analysis of the performance of a building from its conception to its demolition. Keywords related to this are related to different phases or steps inside the life cycle as Life Cycle Analysis, Residential Homes, Circular Economy, End-of-life, etc., and also cover keywords related to existing constructions as Existing Buildings, Refurbishment or Historical Buildings. Few papers focus on the later phases of the building and study how to retrofit the building materials to create a circular economy [4], control the waste produced in buildings during renovations or demolitions [6,27] and the creation of a unified lifecycle via cloud [55]. BIM can also be used in the usage phase to maintain the building [8]. The ways to use BIM in the existing buildings to renovate them are explored in Refs. [59,97] for general buildings and historical buildings [47,83] and a case study for the Portuguese palace of Sintra [48].
- Management and BIM are also related as they can improve the control of the professional on the project to achieve a better result or reduce the working load or mistakes. Some keywords in this area are Collaboration, Information Management, Self-Organisation, Building Management, Lean Construction and Project Map among others. An ontological approach on BIM, its several dimensions, and its project management abilities in each case has been used to define precisely the term BIM [70]. The adoption of the BIM by different professionals and stakeholders can increase the benefits but comes with risks [13,37] which have been listed and prioritized [17] and there are models to evaluate the level of adoption of BIM for companies [100]. In the upcoming years Industry 4.0 is going to be a game changer to reinvigorate the AECO Industry and at present much of the focus is in BIM's implementation [73]. BIM adoption can assimilate a of a multitude data necessary to take asset management decisions across the structure lifecycle

Table 3
Frequency of the keywords.

Keyword	Frequency	Percentage	Thematic Area
BIM	57	13%	BIM
HBIM	8	2%	BIM
Sustainable Development	5	2%	Sustainability
Sustainability	4	1%	Sustainability
Point Cloud	4	1%	Design/Performance
Sustainable Construction	3	1%	Sustainability
Construction Management	3	1%	Management
Existing Buildings	3	1%	Life cycle
Building Performance	2	1%	Design/Performance
Parametric Design	2	1%	Design/Performance
Environmental Impact	2	1%	Sustainability
Collaboration	2	1%	Management
Project Management	2	1%	Management
Performance-based Design	2	1%	Design/Performance
Case Studies	2	1%	Design/Performance
Information Management	2	1%	Management
Demolition	2	1%	Life cycle
Construction and Demolition Waste Management	2	1%	Life cycle
Project Delivery	2	1%	Management
Building Design	2	1%	Design/Performance
Sustainable Building	2	1%	Sustainability
Green Buildings	2	1%	Sustainability
Decision Making	2	1%	Design/Performance
Multi-object Optimization	2	1%	Design/Performance
Energy Efficiency	2	1%	Sustainability
Construction Safety	2	1%	Management
Design Process	2	1%	Design/Performance
Structural Design	2	1%	Design/Performance
Safety	2	1%	Management
Planning	2	1%	Design/Performance
Others	293	68%	

and create an integrated building lifecycle asset management model [8]. To develop a BIM project each step needs to have its right Level of Development [49] and it has to be taken into account that the BIM adoption is different for each country as the regulations are different like in Malaysia [53,93]. Integrating the work sequence and planning and the scaffolding [60] can use BIM during the construction phase. BeaM is a production management system that supports BIM-integrated apps and Lean Construction Management methods [11] on construction sites to improve production rates and reduce inefficiencies and resource waste [86].

In the articles selected there are a total of 311 different keywords from a total of 430 used among all of the articles, being 137 of them repeated in different articles. The keywords are chosen by the authors to describe their work, so it was expected that a lot of the words were unique for each paper, only 32% of the keywords are used in more than one paper.

Table 3 shows the keywords used in more than one paper, there are a total of 31 different keywords repeated among the articles. The most used keyword is *'BIM'* with a frequency of 57 times through the 81 articles. The next most commonly used keywords are 'HBIM' with a frequency of 8, *'Sustainable Development'* with a frequency of 5 and *'Sustainable Construction'* with a frequency of 3. The keyword *'BIM'* was expected to be the most common as it defines the frame where the researches are involved. As the other keywords are chosen by the authors it is harder to find coincidences among them in an exact way.

Comparing the keywords by themselves is not a way to compare the thematic areas among different articles, because the dispersion in the terms creates a dataset with a few repetitions. Only 32% of the total number of keywords are used more than once across the dataset. The comparison has been done strictly, so the words have to match exactly, but there are some small differences across the terms like the use of 'Multi-objective optimization' with a frequency of 2 and 'Multi-object optimization' with a frequency of 1 in different papers. These resembling keywords are treated as different in the countdown but are referring to the same term. So, to establish a comparison about the main topic in the article we have grouped the different keywords into thematic areas, defining a total of 5 different thematic areas, extracted from the cluster analysis. This categorization is shown in Table 3 for keywords with a frequency bigger than 1. Each keyword has been classified into one of these thematic areas based on the concept that they define as seen in Table 4.

Each paper has been classified in one of these areas, based on the frequency of the keywords present in the article (see Table 5). So, an article with more keywords regarding *'Sustainability'* and a few on 'Design/Performance' will be classified as 'Sustainability'. This classification gives an overview of the focus that each article is taking and the general interests of the researchers. The area *'BIM'* has been dismissed from the classification as it is a search criterion and will not be relevant to further study.

The area *'Design/Performance'* is the area with more attention with 44 papers related to it, followed by *'Management'* and *'Sustainability'* with 14 and 18 respectively. The thematic area with less attention is *'Life cycle'* with 5.

The dispersion in the groups for each article show bias in the research towards "*Design/Performance*" researches or publications. They receive around 50% of the research effort while the rest is divided into different areas. In the previous cluster analysis, we can also see that the weight related to the keywords in this area is greater compared to the others. There is also a great interest in exploiting the BIM capabilities for management in the project and the improvement in the sustainability of the project.

3.3. Evaluation of the BIM adoption

A second analysis of the data has been done based on the content of the papers and its scope and using two criteria, the lifecycle of the structure project and the different roles intervening in it. The structure's lifecycle is understood as the different steps of a structural project and it is divided into four phases: the design phase, where the structure is conceived and designed to be built; the construction phase, where the structure becomes a reality and starts to be functional to the whole building; the use phase; where the structure is put into use; the last phase which is the demolition phase, where it is destroyed and its waste managed. Several agents work to make this process possible, being: architect, engineer, constructor, and user. They interact with each other during the different phases in different extents [28] From it, a classification method has been developed to sort the different researches and help to extract the conclusions (see Fig. 6).

After carefully studying the papers obtained in the search it is observed that despite having used the term "structural project" as a search criterion, the found researches were not affecting only this part of the building project. In fact, most of the papers continue to take a generalist approach when implementing BIM, without a focus on the structural project or any of its phases, neither being directed to any of its different agents. But there are still some papers that directly affect the structural project, even if not exclusively.

Table 6 shows the number of articles directed to each of the agents at each step of the life cycle (see Table 5). Papers oriented to multiple agents or phases are considered in both of them. There is a focus on the design phase, where most of them are directed, and the second most area of focus is the construction phase. There is not a clear preference among the architect and the engineer roles, while the constructor is receiving less attention and the final user is commonly left behind.

In addition, the studies which treat the structural life are not only focused on one of the different phases of the previously stated

Table 4
Number of keywords in each thematic area.

Thematic Area	Number Keywords assigned
BIM	81
Design/Performance	138
Sustainability	38
Management	72
Life cycle	30

Table 5
Frequency of the papers for each thematic area.

Thematic Area	Papers related
Design/Performance	44
Management	14
Sustainability	18
Life cycle	5

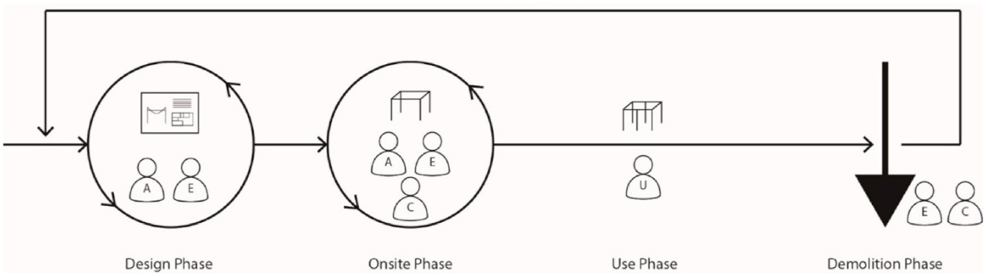

Fig. 6. Structural lifecycle phases and agents intervening.

Table 6
Articles' focus distribution.

	Design Phase	Construction Phase	Use Phase	Demolition Phase
Architect	51,00	25,00	17,00	7,00
Engineer	57,00	26,00	19,00	8,00
Constructor	33,00	32,00	11,00	11,00
User	5,00	3,00	7,00	3,00

lifecycle, but in most cases, they affect many of the phases and some of the agents, as shown in Table 6. This could be expected, as the process is complex, non-linear, and with a lot of interactions, as defined. So, isolating what is only related to one phase is almost impossible, because there is always a constant interaction between the different people at each step. Due to this fact to be able to properly study the actual trends, two additional tables have been developed where the agents and the phases for each paper have been isolated. This tables shows only the number of papers related to each phase or agent and not the actual classification for each studied document, which can be found in Table 6.

3.4. Spread of the studies by agents

In Table 7 it is shown the spread of the studies by the agent to whom it is directed. There is a focus on the Architect and Engineer to whom are directed around 75% of the studies, and a clear disinterest for the User with 8 papers taking him into account. As BIM is a technical tool focus is on the agents who are going to make use of it and not who is going to take profit from its product. So, most researches are focused on the use of BIM for improving the work of these three agents, creating assets or easing their duties.

Most of these papers do not clearly distinguish to which agent they are directed onto and up to 35% of them aim to improve the work of the three main agents. This means that BIM research is not clearly focused on one of them but on the whole project as it can generate an impact that affects all of them.

Studying the topics being researched they are meant to work as a design or management tool. In this way, the User does not have a clear role as he is not a technical agent and can only receive info (and the building itself) and not interact with the data. So, the User will very rarely interact with BIM environments during the building's life cycle.

3.5. Spread of the studies by phase

The data sorted by phase shows an interest in focus during the design phase as a total of 81 out of 81 articles touch this topic. This proves two points; in the first place, it shows the BIM's ability to enhance the procedures and affect the design phase in many ways,

Table 7
Spread of the studies by Agents.

Agent				
	Architect	Engineer	Constructor	User
Total	59	66	45	8
Percentage	72,84%	81,48%	55,56%	9,88%

taking advantage of its features as a highly intercommunicated database. In the second place it creates an uneven distribution of the interest in the research, the academia is focused only on one part of the life cycle, leaving the rest almost blank.

It can seem that BIM environments cannot add up any value to these stages of the project, but it seems unlikely considering the time-managing capabilities of BIM environments. Most of the research is focused on design because it is also the phase where most of the decision is taken. Design phase decisions influence the other three [Fig. 7], even if that decision is not put into account until later on. So, as most of the research is looking into simulation or managing tools it is not surprising to having the most impact on the design phase.

Analysing the cross-relationships between the different phases a trend is shown. There is a link between the design phase and the other three. As a starting phase, the design phase has great importance in the life cycle and the research key shows that it is key to implement any new improvement by the use of BIM. It is the most important phase because most of the decisions are taken during its influence in the posterior development of the building. Design phase has also influence during the life cycle of the building as some solution need to be 'designed' or 'analysed' in order to perform operation of maintenance, rehabilitation or demolition, among others.

4. Discussion

4.1. General overview of research topics

The developed bibliographic review brings us a huge perspective over the state of the integration of the structural in BIM environments, its level of adoption and understanding. As well as the different applications and limitations located until now. The BIM horizon is really quite far away and this technological process has a long way to go, but the work presented here shows a general overview on the topic. On the one side, the older papers show more general ideas about the BIM adoption in the structural project performing a qualitative approach. On the other side, the papers published in the last years are presenting more specific approaches or even some Building Performance Simulation Tools (BPS Tools) and the results obtained after using BIM on real projects. This means that the research lines pointed by the first papers are starting to be looked at.

Most of the studies are focused on the design and construction phases and directed to the architect or the structural engineer. This fact remarks a trend about the use of BIM to take decisions and its great capabilities as an analysis tool for the project [56] especially in the fields of sustainability and regulations requirements check-up. In this regard, some of the papers address and quantify if BIM has incorporated correctly the sustainability into the project [31,66] or embodied energy [90] and others study the real ability for BIM to incorporate the sustainability into the project [3]. The use of BIM to achieve the Green Building Certificate in Australia is studied [99]. SimulEICon is a BPS Tool to incorporate sustainability into the project assisting the decision-making by checking the best option for environmental impact through an NSGA-II genetic optimization algorithm [77,92] and the automated design of concrete reinforced structures [1]. However, we also can find papers that look further than just implementing sustainability into BIM, as there are researchers presenting a way to incorporate and verify the Malaysian Building Code [93]. It is also important to highlight the discussion about the right Level of Development of a project in each of its phases [49] and about the risks of making BIM take decisions without any further extra control [42]. Tools to specific tasks as automated planning of concrete joint layout [88] are being developed.

The evolutive n-dimensional capabilities of BIM get taken into an advantage in the studies, using them to introduce new variables and criteria into the model as its development progresses to adjust the level of analysis to the existing data at that exact point and assist in the decision-making process. This allows the professional to use new design variables and effects among them that are difficult to quantify (either numerically or theoretically) or with a lot of uncertainty. Nowadays it has been used mostly as a way to incorporate the sustainability and risk management criteria [104] structural safety problems [103] and fault detection [35] in the construction as we have shown with the previous examples. The combination of BIM and Multi-Criteria Decision Making has been an increasing research topic and there is a literature review examining 45 different articles and their applications [94].

But there also exists a great number of studies that aim at the construction phase. Unlike the previous ones, there are not many tools to assist in the design, as the project has arrived at a phase where most of the decisions had been already taken, but we can find papers

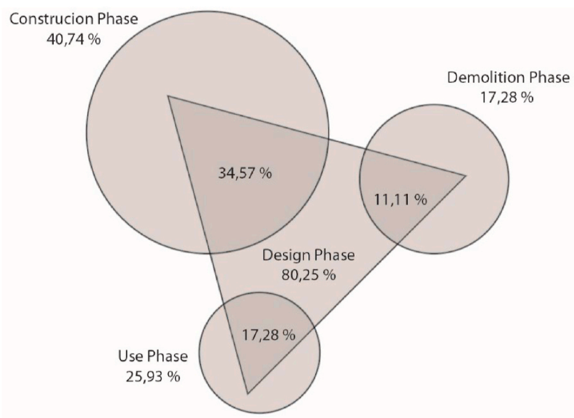

Fig. 7. Percentage of articles for each phase and in common with the design phase.

dedicated to the management and planning during the construction. These are the cases of articles that pretends to quantify the CO2 emissions at the building site [67] and that explore the BIM ability to handle the quality control [26]. Moreover, we can also find another set of papers, which is small in raw numbers but not less important, focused on the real-time building's monitoring to improve the construction management [71,101] which generates as-built structural models through laser scanning data. There is a study on the application of BIM for infrastructures [18], a field less studied as most of the papers are destined to buildings. Apart from these lines, the use of BIM to create security plans during the construction phase including factors like secondary structures or the movement of the different working crews has also been assessed [60].

As a conclusion from Table 8 and according to the bibliography [65] there hasn't been a great research effort into the use of BIM during the demolition phase. This can be understood as a real lack of uses for this phase or simply a lack of ideas. As opposed, there have been presented and studied different possibilities for the use of BIM in this phase [5], showing its viability [51]. A method to estimate the waste generated with the demolition or the renewal of a building has been proposed [27] and a tool to quantify how much of this waste could be used in a future building or rehabilitation base on the different materials and constructive systems used is shown [4].

Without any doubt, the less explored phase regarding the use of BIM in the structural life cycle is the importance of the project's end-user in its life, despite the fact that he is directly responsible to maintain the structure once built. The role of the user as a mediator between the design process and the demolition is essential for the building. He provides relevant information about the initial design, state, and modifications suffered by the structure to plan an adequate maintenance and demolition [97]. Being these, key data to guarantee sustainability and proper waste management in the project. It is also remarked that the sustainability strategies must differ at each country's level of BIM adoption [2] and on the project's Level of Development to develop these tasks [49,98].

In recent years an interesting research trend has appeared regarding existing buildings mostly using BIM to preserve the patrimonial heritage, which is known as HBIM or Heritage-BIM. There have been several research creating BIM models of patrimonial buildings using point cloud or laser-scanning technologies for different historical buildings across the world like Seville's Cathedral [10], the New Theatre of the city of Bologna [69], Four Courts building in Dublin [36], Yingxian Wood Pagoda [54] and Flaminio Stadium in Rome [33] among others. These papers present a methodology to create models from existing buildings of different materials and necessities, model its decay [29] and preserve it. They also perform a structural analysis after having created the parametric digital model, to study the structural behaviour [16].

4.2. Analysis SWOT

The general overview made in the later section describes the actual state of the structural project integration into BIM. The following Strength, Weaknesses, Opportunities, and Threats Analysis (SWOT) is to create a conscience of the actual points where and advancement has been achieved and those in need of further research and more resources, as well as the threats that this technology is facing (see Fig. 8). This analysis is really important as it shows a way to continue developing BIM without wasting research efforts in already done studies.

The implementation of the structural project into BIM environments has a lot of strong points in favour, either to continue improving the results or to contribute with new benefits. In the first place, one of the most favourable points for this adoption is the big number of researches and researchers working right now on the topic. In this article eighty-one papers have been studied and that is just a sample of the total number of papers that continue growing every day. Because there is a lot of people working on it. The knowledge advances quickly and from different points of view. In the second place, the great advantages that BIM methodology gives to the structural project are highlighted, like the automatization of the processes, the constant review of the data, the easiness to apply the Lean Construction philosophy or the sustainability criteria. These advantages help in the process management or the different aid capabilities for the structural design [68] among others. In third place, there are different processes and applications developed to assist the decision-making that has been created and it is starting to be used on a professional level, extending the use of BIM over academia. In the cases where this adoption has followed the right course, it has always provided direct benefits to the business (economic benefit, better productivity, or more competitivity) as the analysed papers show. Improving income and productivity around 7% and 12% according to the bibliography. Finally, the governmental interest for the BIM adoption in public projects favours that the private business allocates more resources to this research and development. This governmental interest is producing a huge adoption of BIM by stakeholders. The adoption of the BIM methodology by private businesses is growing every day.

There are also a series of weak points, some of them inherent to the methodology and some of them caused by the ignorance or disinterest of the actual researchers. The great amount of research effort is also a disadvantage. The great advance speed is truly an advantage as stated, but all these people are not working co-ordinately, so there has been noted some overlapping among different researches, especially in the structural design tools to apply sustainability criteria. Another weak point is the difficulty in its adoption, not caused by the complexity of the methodology but by its different modus operandi compared to the more traditional methods that are used nowadays in the AECO Industry. If BIM is not rightfully implemented and the methodology adapted to it, it can produce more

Table 8
Spread of the studies by Phase.

Phase				
	Design	Construction	Use	Demolition
Total	65	33	21	14
Percentage	80,25%	40,74%	25,93%	17,28%

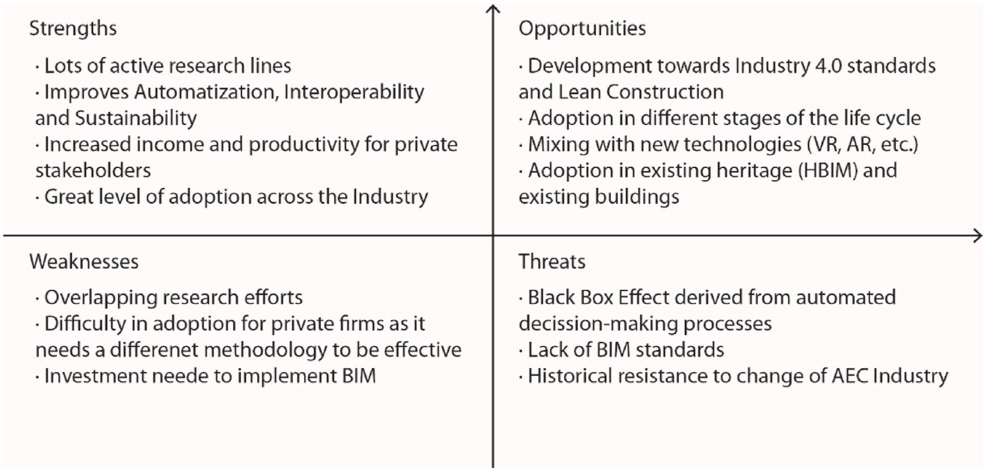

Fig. 8. Results of the SWOT analysis.

barriers than accomplishing advantages through the project. If we look at the use of BIM by the Industry there are also other disadvantages. Right now, BIM is an emerging tool and it needs development inside a business to be useful. To use it, the employers must make an effort in time and money to form their employees and to develop an effective BIM methodology also known as BIM Executive Plan or BEP. It is not strange to find that starting to use BIM has led to losses in some companies. Most authors agree that it is better to start to use BIM with projects that are already known for the company and not start using it when also expanding the business scope, else BIM can easily overburden the workload resulting in a negative implementation. That effect is significantly accused of certain types of projects, like rehabilitation ones, as the investment in time to create a valid geometrical model can mean a huge investment in time considering the possible scope of the project, which is currently assessed through laser scanning, point cloud and related techniques.

The BIM potential has not been fully revealed yet and there exist several possibilities to continue advancing and improving the development of the structural project in them. On the one side, nowadays there are a great number of open research lines that are not exhausted like the ones presented in this paper, most of them are focused on the use of sustainability or energy efficiency as a design variable, although there are lines that look for the economic efficiency or the use of optimization algorithms with different purposes. Besides these opportunities to further advance or complete the open lines, there exist a lot of points that are lacking further research, for example, ways in which the user of the building can benefit out of BIM, either using it as a database to have more knowledge about their building [96] or to be a messenger between the professional in the construction phase and the professionals in charge of future rehabilitations or the demolition. The employment of technologies to develop BIM Models from existing building via laser scanning, point-cloud techniques or similar and the posterior analysis of the model is also an open research line. Also, the use of BIM in the demolition phase or to study and improve the building can be deepened. And there exist some research lines with great potential yet to exist, as mixing BIM with Virtual Reality technology as a design tool or mixing it with 3D-printing, which can greatly improve the precast industry, as many others as some authors point [13,37]. Even if the research about the structural project in BIM is quite diverse and extensive there are a lot of possibilities still to explore and we can't foresee where the limits for these new paradigms are.

To achieve the right development of these opportunities it is necessary not only to continue with the research but to be conscious of the threats existing the BIM adoption, the risk of failure, to be able to avoid them or diminish their effects. These risks can't always be seen at first sight and that makes them harder to avoid. One of the biggest BIM threats is the errors caused by the Black Box Effect [42], derived from that automatization of any process whether it is design or verifying related. This term defined by William Cauer [23] refers to any automatized process in which the user inputs data and obtains an output without having any control in the intermediate process. In the literature [42] an extensive review of the different mistakes that can appear by this effect in the structural project development and possible ways to deal with them can be found. Another risk to solve is the intellectual property of the project. The BIM business model is not adequate to the traditional contracts where every agent is contacted separately. BIM works best with an Integrated Project Delivery (IPD) kind of contract, where every agent works over the same model and the client receives it when it is fully finished [24]. This causes responsibilities and intellectual property issues that are not solved in the contractual models used nowadays, but a contract that covers this market demands must be found. The major reluctance for the AECO Industry to adopt BIM and therefore one of its main barriers is the resistance to change by construction stakeholders, inadequate organization support and lack of BIM industry standards [25].

4.3. Research gap

The integration of the structural project on BIM environments it's a paradigm in development. Its main objective is to develop a framework to control the structural project in any of its phases via BIM environments. Every aspect of the structural project can be assessed with this approach, providing advantages over more traditional methodologies. Currently, the research has developed design tools which reduce operational time for professionals and enhances their results. In the current of the research in BIM, several gaps have been pointed out by the different analyses on this paper. The research gaps are defined as grey areas in the research field and less interest has been given to them.

The general interest is centred on certain research areas related to design or performance tools, mainly used for sustainability or management. Several papers present approaches on unifying BIM and Sustainability assessment (such as CO_2 emission analysis, resource optimization, achieving greener certificates, etc.) and several ways to increase the efficiency of the professionals to develop or manage the project. As it has been presented, 80,25% of the analysed papers are destined to be used during the design process of the structure. This leaves the other phases of the structural life cycle almost unexplored. The use phase and demolition phase received the lesser interest with only 25,93% and 17,28% of the publications taking them into account. Using BIM in all the phases of the life cycle ensures the coordination between them thanks to its time-related dimension.

The different thematic areas presented in this paper have received less attention from the researchers. In the starting years studied the thematic areas were more diverse and new trends were opened, but in later years the research has been more skewed towards sustainability and new horizons in the Industry as Industry 4.0 or Construction 4.0. This change can be a result to reduce the impact of the AECO Industry on climate change with BIM. Some papers present the BIM possibilities on building maintenance and demolition and its value as an information source for the structural life cycle. These researches point towards a new understanding of BIM, being useful as a database more than as a design tool. Further research in building renovation, maintenance, and demolition with BIM can influence the ecological impact of the AECO Industry in climate change and reduce CO_2 emissions from the industry.

In the early years studied, the trend was to develop theoretical approaches to the problems or objectives. Later on, case studies and Building Performance Simulation Tools have been appearing showing the real capabilities of BIM. As the research advances, new approaches have been presented. One of the new lines is the use of BIM for Historical buildings, opening new research fields and pointing at their difficulties. These new research lines are starting to be developed in a theoretical approach, but as presented there are also some practical uses. New research lines find new challenges and barriers that are being overcome. HBIM researches are starting to implement scan-to-BIM point-cloud based techniques to deal with the difficult geometries of historical buildings and perform structural analysis with great results as has been shown in previous examples.

5. Conclusions

5.1. Summary

In this article, a literature review of the use of BIM in the structural project has been done in a two-way approach. On one side an informetric approach has shown that the use of BIM in the Structural Project has gained more attention through the years and it is still a topic with growing interest, as the growth in publications per year shows. This general analysis has been used also to determine the main journals working on the topic and how the publication rate has evolved over the years. On the other side an analysis over a few selected articles to establish its thematic areas and focus based on their keywords and contents. The combination of these two different approaches gives a full comprehension of the state of art BIM adoption for the structural project that has not been done before.

A total of 81 articles published in high-impact journals have been reviewed showing the different research lines open about the integration of the structural project into BIM. Among them, the number of articles regarding bibliographic reviews and theoretical approaches is larger than the articles which present Building Performance Simulation Tools. This big difference in research effort is diminishing in the last years, due to the adoption of BIM by the private sector and the growing demand in using BIM by the different countries' governments.

Also, an analysis regarding the structural project life cycle, from the design phase until the demolition phase, has been developed and the different agents implied in each phase have been defined in addition to their functions at each step. This whole process has been cross-studied with the found research lines determining the points in the structural project where right now there exists a major and a minor focus.

Once the trends and the main focus points in the papers have been found and classified a SWOT analysis was conducted to study the overall development of the structural project in BIM. This analysis shows the strong point of the BIM technology and methodology, the disadvantages that it is currently facing, and possible ways to overcome them and continue its development in the future. We have also listed some possible risks which can affect the right development of BIM in the near future.

5.2. General remarks

After performing the literature review across 81 research articles considering the integration of the Structure Project in BIM environments, we can extract some important remarks:

- The scientific production proves that the integration of the Structural Project into BIM environments is a reality and they both are creating a symbiotic relation. In the studied time period, there has been a progressive adoption and development of BIM in the Industry developing methodologies and BPS Tools to improve the results of the structural project in several ways.
- The research is focused on developing tools and software that aid the professionals, mainly architect and structural engineer, during the design of the structure. Examples of tools to incorporate sustainability criteria in the structural design have been found and studied and also other tools related to management, structural optimization or performance.
- Some points in the life cycle, like planning in the demolition phase, the proto-design of the structure, or the role of the user in the utilization phase; need further research, while in others such as sustainability-based BPS design Tools is starting to be a repetition of the processes.

- In later years there has appeared a shift in the research trends. Nowadays the research is heavily focused in two main topics: Sustainability and Industry 4.0. There has been also a growing interest in the use of BIM in heritage or patrimonial buildings (HBIM) creating and analysing models via scanning techniques.
- While the research interest is still growing and gaining knowledge every year, there are starting to appear barriers and threats that need to be overcame such as the Black Box Effect, the lack of effective standards and the reluctance to change in the Industry.
- The 'digital revolution' also known as Industry 4.0 is becoming a reality in the society, advancing towards a productive system with increased interoperability, automatization and more sustainable. BIM is one of the few ways that the AECO Industry has to effectively take these social demands and improve itself.

5.3. Future research lines

As a result of the bibliographical research, we have determined different trends in BIM research and have found that these trends have been different across the years. In later years, most of the research has been focused on Sustainability related topics and how to assist or improve it during the design phase and some redundancy in the topics is starting to appear.

The use of BIM during the service life of buildings can be very beneficial. Cloud-point technologies are starting to be used to create geometrically accurate models of a building to further study it. Building renovation is a growing interest for the AECO Industry and the real state of the building needs to be analysed. BIM environments are perfect to capture accurately the differences between reality and design and analyse its implications, but have difficulties capturing the particularities of existing buildings as they excel with standardization and not on individualization. Structural necessities can be better understood with BIM and its rehabilitation can be optimized according to its deterioration and damage. BIM has proven helpful during the design phase, but its capabilities can also be used for maintenance, renovation or even during the demolition as new research in HBIM is proving nowadays.

Definitively, the use of BIM to develop the structural project has advantages through the whole structural life-cycle and nowadays this is starting to be a reality. HBIM research show that BIM can be used on existing buildings and help to analyse its behavior, despite some difficulties with the creation of accurate models. Lots remain to be done and the full potential of BIM is unknown. Some weak points and challenges are arising and they need to be solved to guarantee the best results when using BIM. The research field is opening and new horizons are appearing. The true potential of BIM environments for the structural project is starting to unveil.

Declaration of competing interest

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

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