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Trends, Problems, and Solutions from Point Cloud via Non-Uniform Rational Basis Spline to Building Information Modelling: Bibliometric and Systematic Study

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Abstract: Building Information Modelling (BIM) has found applications not only in the planning and designing of new buildings but also in project monitoring, record-keeping, and analyses of existing structures. In addition to its primary application, information modelling spreads to other areas, developing solutions for their specific uses. This study engaged a mixed-method literature review according to the extent of the pool of knowledge for two research steps between three concepts—from point cloud to NURBS and then from NURBS to BIM. In the first step, the keywords point cloud and NURBS were analysed using scientometric methods. In the second step, a systematic analysis of the content of works obtained with the keywords NURBS and BIM is presented, extracting problems and proposed solutions for information transfer technology. The results of a quantitative analysis identified major trends, (1) research is distributed in interdisciplinary and multidisciplinary areas and historical (heritage) modelling is the highlighted one, (2) development of technologies for object surveying, and (3) the application of data in different engineering fields, while a qualitative analysis points at problems in (1) model building, (2) interoperability, and (3) automatization. Solutions such as mixed models, multi-layered models, a mix of formats, or bridging elements (semantics, proto-model) are proposed.

Keywords: BIM; point cloud; NURBS; application; HBIM

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1. Introduction

Building Information Modelling is an evolving technology in the architectural, engineering, and construction (AEC) industry, with its components developing simultaneously, contributing to its overall growth. Liu et al. (2019) found that BIM is evolving as a scientific area where research identifies trends and advancements for application in construction sites [1]. The construction industry currently needs to catch up in innovation and digitalisation but aims to optimise resource usage, reduce project costs, enhance productivity, and improve document quality [2–6]. Challenges facing BIM integration in the construction industry include a lack of senior management support, inadequate BIM-skilled workforce, adherence to traditional processes, and limited awareness of BIM's importance in circularity and sustainability [7]. Since BIM's development began, sufficient results have been produced for a systematic review. Some works focus on the development and results of BIM applications in specific areas (infrastructure, green building, facility management), while comprehensive reviews often highlight the need for global and regional BIM studies [1]. These reviews emphasise the work of author Zhao (2017), who analysed 614 references from the Web of Science database in 2005–2016, a broad survey of articles with the keyword "Building Information Modelling, BIM" [8]. The research identified authors, author networks, and terms in the papers. The analysis of keywords identified ten prominent concepts in order: Building Information Modelling, system, model, design, management, simulation, project, industry, and technology. Besides these fundamental terms related to BIM, six additional terms that cluster citations were identified: Building Information Modelling, interoperability, three-dimensional model, visualisation, and industry foundation classes (IFCs). Liu et al. (2019) conducted a more extensive scientometric analysis, analysing 1455 articles, and highlighted trends in BIM development, including augmented reality (AR), geographic information system (GIS), and Internet of Things (IoT) [1]. By analysing keywords and their connections, authors identified terms such as BIM, adoption, interoperability, 4D, cloud computing, generic algorithm, energy efficiency, and augmented reality. Finally, the authors concluded that the latest BIM development stage focuses on transferring innovations from BIM to other industries. Baghalzadeh Shishehgarkhaneh et al. (2022) examined 1879 academic references from the Web of Science database regarding the use of BIM, IoT, and Digital Twins (DTs) in the construction industry using a bibliometric and systematic literature review [9]. Authors found that BIM, IoT, and DT in construction, Historical or Heritage Building Information Model (HBIM), Smart Contracts, BIM, Ontology, and VR and AR in BIM and DT are the main study themes. Besides main themes, they identified several prospective areas for future study, including BIM and Metaverse technology, BIM and Artificial Intelligence (AI), Metaheuristic algorithms for optimisation purposes in BIM, and the Circular Economy with BIM and IoT. The dispersion of terms into various fields indicates the significant potential of new technologies that impact BIM and heralds the emergence of new specialised research niches that need to be filled.

Since the introduction of Virtual Design and Construction [10], this technology has found applications in various areas, scales, and uses [2]. The basic division into as-designed BIM and as-built BIM offers a different set of technologies and methods for these two segments of BIM [11]. Further differences can be observed in the research paths for as-built and heritage tasks [12,13]. The results indicate significant differences in the use of standardised BIM formats and objects among disciplines collaborating on HBIM models, with standardised BIM being more prevalent in construction modelling than in the field of the conservation or visualisation of heritage buildings [13].

A 3D point cloud is a dataset of x, y, and z points defining a volume and surface. The technology for collecting point cloud data is rapidly advancing, with a growing demand for its application in ACE/FM. Review papers point to various techniques and methods for transforming point cloud data into a construction model [11,14], while Wang and Kim (2019) identified three critical applications of point clouds in a review of 197 works: the 3D model reconstruction of semantic and geometry models, geometry quality inspection, and construction progress monitoring [15]. The same authors also point out research gaps, such as identifying application information requirements, semantic enrichment for as-built BIM, and demands for geometry quality inspection in the fabrication phase. The last gap would be research in visualisation for VR/MR technologies. Integrating point clouds into BIM modelling requires technological creativity and skill in handling this technology. Applications will undoubtedly continue to advance, develop, and diversify in the future. This paper analyses the literature in this area using a method that enables an extensive literature analysis.

A non-uniform rational basis spline (NURBS) is a mathematical function to create two- or three-dimensional objects that improve flexibility and precision in developing modelling systems for diverse industrial branches such as the computer-aided design of the vehicle industry, of the packaging industry, or for animated characters in movie production or computer games [16]. These mathematical relations are used in computer graphics to construct shapes and models mathematically. The use of NURBS for transferring geometric data from point clouds to models falls within the multidisciplinary engineering field. Articles from the early 1990s mainly focus on mathematical expressions that define NURBS, with only a few considering their application in CAD [17–19]. Articles dealing with the application of NURBS in the BIM concept are more recent and date from 2014 in the WoS Core Collection, with the most works coming from remote sensing, imaging science, photographic technology, archaeology, and computer science interdisciplinary applications.

This paper uses scientometric methods to explore the literature on the connection between point clouds and BIM models through NURBS as usual methodology for constructs that emerge in different scientific fields and subject categories (see [20,21]). This area is relatively new in the field of BIM modelling, and the concepts of point cloud, BIM, and NURBS have their origins in various fields such as mechanics, engineering multidisciplinary, and mathematics interdisciplinary applications, and appear in areas like applied physics, robotics, and optics. The most common application of connecting these concepts is in the field of heritage, historical BIM, as-built BIM, and twin models. The literature review aims to identify trends and gaps in two stages of connecting these three concepts—the connection of the point cloud and NURBS, and NURBS and BIM. Trends and gaps indicate the direction of development in a particular area and unexplored or insufficiently explored segments that point to a problem or missing support in development. Research questions were raised as follows:

(1) In which disciplines and scientific fields is knowledge about the relation of point clouds and NURBS dispersed, and how is that knowledge represented?
(2) What prevailing problems and solutions occur when transforming data from NURBS to BIM? How can they be clustered?
(3) What are the research gaps and current edges in disciplines in data transformation from the point cloud via NURBS to BIM?

This research adopts a qualitative analysis method to analyse 166 journal articles related to the point cloud, BIM, and NURBS published during 1997–2022. In the qualitative analysis, 140 bibliometric records were imported into the scientometric toolkit for a visualisation analysis to visualize the network of co-occurring keywords, author co-citation network, and document co-citation network. In addition, co-citation clusters were identified, and a critical review was conducted for the top three documents in each cluster.

These bibliometric and systematic studies try to understand the interactions that exist in fields that use the point cloud, NURBS, and BIM as tools or data to identify the main problems and challenges in the interactions of these concepts. At the beginning of the article, in the part that elaborates on materials and methods, we present the workflow in which the main concepts interrelate and the analysis framework is visualised and explained. Results are presented for the bibliometric and systematic analysis. The bibliometric analysis is presented and discussed with a visual presentation of author clusters, simultaneous subject categories, and a co-occurring keywords network analysis. The systematic analysis is presented and discussed with descriptive elaborations of lessons learnt, and studies and authors are grouped around common concepts for problems and solutions within the field of data transformation. The discussion and results section mentions the limitations of the methodology and results, and indicates future research and challenges.

2. Materials and Methods

This research aims to identify the problems within the data transformation from point clouds to complex data systems in BIM (parameters, interrelated objects etc.). To achieve this aim, a mixed-method literature review was selected according to the extent of the pool of knowledge for two research steps between three concepts—from point cloud to NURBS and then from NURBS to BIM. The authors combined a scientometric, bibliometric approach and a broader amount of articles for the first step, and a systematic approach and a smaller number of identified articles for the second step. In the bibliometric study, author clusters, keyword clusters, and a keyword co-occurrence analysis were adopted to visually explore the research databases, the distribution of the domains, and the main research trends in design team interactions. A systematic review was used to identify the knowledge domains and determine the most frequent problems and the solutions presented by researchers under these domains. It enabled the evaluation of both the historical progress and the main research directions to assess the status and growth trend of the research field.

The literature review was structured around the keywords BIM, point cloud, and NURBS as essential terms in the data transformation methodology to an object-oriented model (Figure 1).

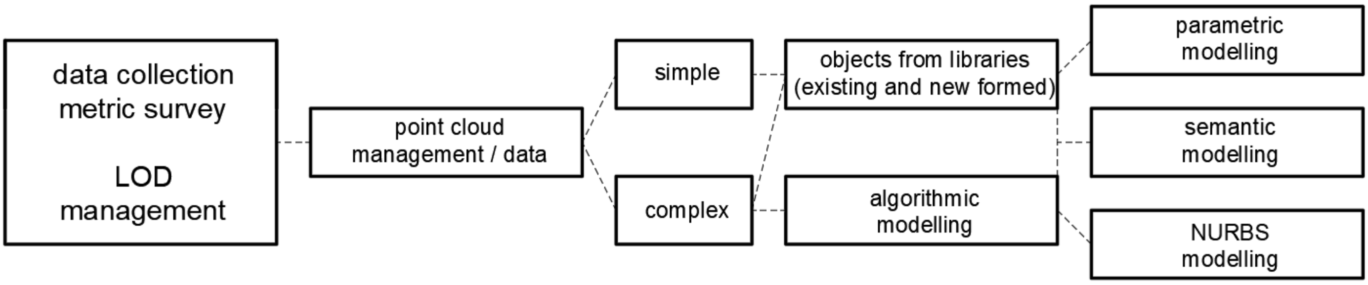

Figure 1. From point cloud to BIM workflow (adapted from [22–24]).

The research framework encompasses the definition of the literature database, search criteria, data processing, and the analysis, as depicted in Figure 2. The paper selection process in this study followed the methods used in other review articles (e.g., Liu et al., (2019); Zhao, (2017) [1,8]). The connection of keywords followed the methodology of connecting point clouds, NURBS, and BIM (Figure 1). One hundred and forty articles in the Web of Science Core Collection database link the point cloud and NURBS. These articles date from 1997 to the present (May 2023). Only a few articles in the Web of Science Core Collection database connect the terms BIM and NURBS. The works include articles and conference papers since innovations are often presented at conferences to share new results with experts and the wider public. Filtering was also based on reading abstracts, titles, keywords, and research questions as well as conclusions and lessons learnt. In the second step, articles were read thoroughly. We identified 26 such articles, which date from 2014 to the present (May 2023).

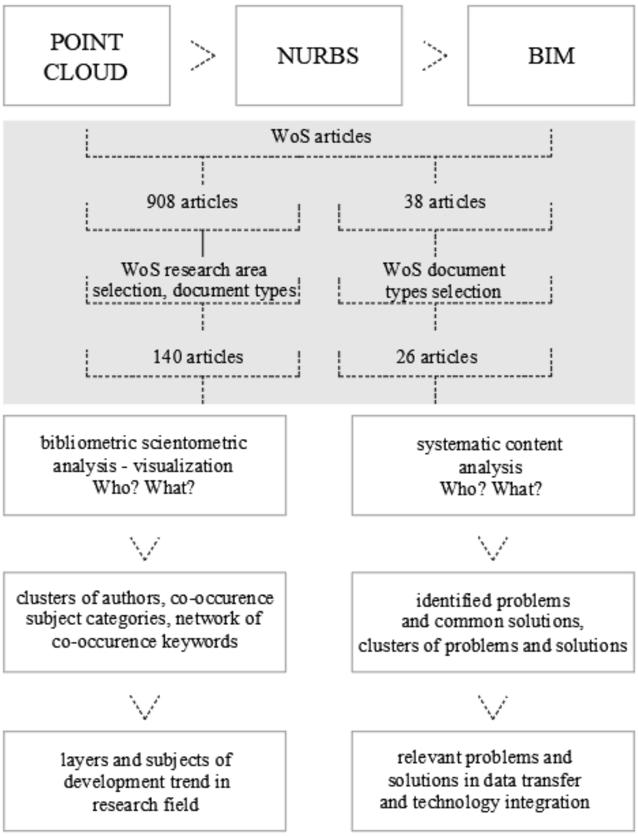

Figure 2. Diagram of the methodology framework.

The publication dynamics of articles indicate that the area connecting point clouds and NURBS began to develop significantly earlier, resulting in a more intensive publication of articles. For this reason, we opted for two approaches to analyse the collected literature. The first group of articles (140 article works; point cloud* NURBS*), bibliometrically analysed, was processed using the CiteSpace 6.2.R4 software package, which allows data extraction from more articles. The second group of works (26 works; BIM* NURBS*) was analysed systematically and qualitatively, reviewing the content according to defined analysis objectives.

3. Results and Discussion

The study analysed articles in the WOS Core Collection database. The researched articles were searched using the keywords "point cloud*" and "NURBS*." Due to the comprehensiveness of the information, the analysis included articles, proceeding papers, book chapters, early-access publications, and review articles. Ultimately, a total of 140 bibliographic units were collected by mid-April 2023. The first article that used the keywords "point cloud" and "NURBS" was published in 1997. Therefore, the temporal span of the bibliographic units covered in the literature review is 26 years. CiteSpace 6.2.R4 software was used to process the collected scientific material, which allows for a scientometric approach to analyse and visualise the literature, discover implications hidden in a large amount of information, and track the boundaries of development [25,26]. This software enables systematic knowledge mapping by creating different graphs and analysing the literature that connects the terms "point cloud" and "NURBS". CiteSpace 6.2.R4 was used. This analysis applied bibliometric techniques of author clusters, simultaneous subject categories, and a co-occurring keywords network analysis.

3.1. Clusters of Authors

The author analysis not only shows the distribution of highly cited authors and identifies influential scholars in the research field but also helps with understanding the distribution of research topics as well as the value and strength of different subthemes. The software summary highlights major clusters including citing articles and cited references. The importance of nodes is summarised in terms of citation-based metrics, such as citation counts and citation bursts, and network-based metrics, such as degree centrality and betweenness centrality. Sigma is a combination of both types, i.e., burst and betweenness centrality. There are fourteen clustering blocks presented as node clusters in the Figure 3. Cluster #0–Cluster #13 represent thematic scopes of the cooperative groups in different research directions. The largest group is a forty-five-author group with a focus on geometry modelling—natural objects led by Requicha (1999) [27] and followed by Bajaj et al. (1999) and Dimas and Briassoulis (1999) [28,29]. The next cluster gathered twenty-nine authors with a focus on archaeological heritage—wooden ornamentation with leading authors Roma et al. (2014) [30], followed by Munro et al. (2016) and Piegl and Tiller (1999) [31,32]. The same number of authors clustered around CNC machining and the major citing article of the cluster is by Bae and Choi (2002) [33], followed by Vaitkus and Varady (2108) [34]. Twenty-six authors are gathered on reverse engineering with three leading articles' authors, Sansoni and Docchio (2004), Besl (1990), and Wang et al. (2018) [35–37]. Clusters #4–#6 have the same number of authors—twenty-five—as a critical literature review, geometry parametrisation, and heritage place—data-driven conservation action with major citing articles by Barazzetti (2016), Safari et al. (2013), and Bolognesi and Fiorillo (2023) [38–40]. The other groups, #7–#13, are working on the rectangular domain, 3D surface, a repair method of a point cloud with a big hole, direct boolean intersection, as-built modelling, nature-inspired optimisation approaches, and improvement in the 3D digitisation process—a reverse engineering process again [37,39–44]. Results indicate three main thematic groups authors have gathered around: (1) historical or heritage modelling (archaeological heritage—wooden ornamentation, heritage place, and reverse engineering), (2) technologies and processes dealing with geometry (geometry modelling, geometry parametrisation), and

(3) the industry application of technologies (CNC machining, reverse engineering process; see [45,46]). Additionally, there is also a significant number of authors belonging to "a critical literature review" theme, pointing out that the field already reached mature status.

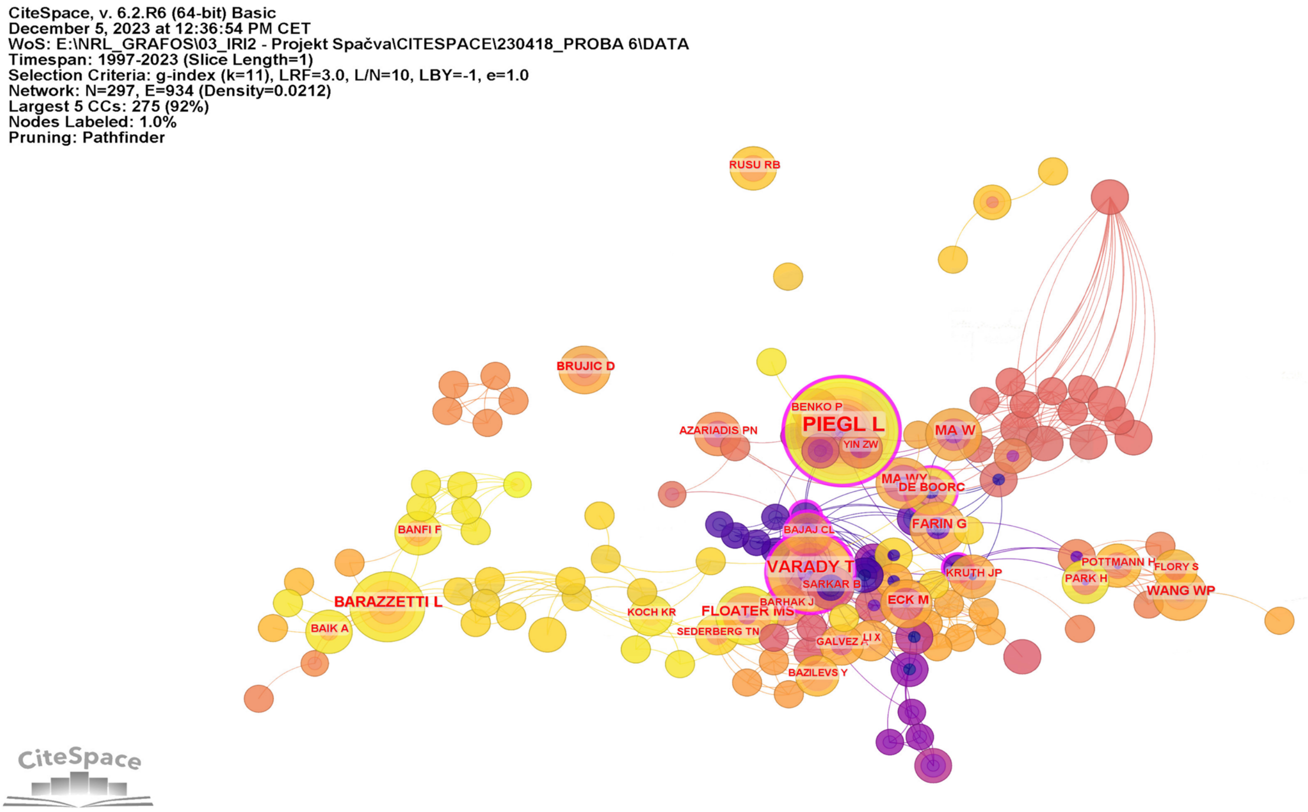

Figure 3. Thematic clusters of authors (CiteSpace 6.2.R6 software).

3.2. Network of Co-Occurring Subject Categories

Subject categories are an integral part of every WOS Core Collection database publication. The network of co-occurring subject types in this research that connects the terms "point cloud" and "NURBS" was produced to analyse emerging trends (Figure 4). The analysed network identified 31 clusters of co-occurring cited subject categories. The Modularity Q parameter with a value of 0.8111 suggests a reasonable network division into weakly connected clusters. In contrast, the Weighted Mean Silhouette parameter at 0.9508 indicates high homogeneity of defined clusters.

Of the total number of clusters (39), 13 clusters were identified as relevant due to their size (CiteSpace manual, p. 15). The label "#0" in front of the cluster name represents the highest number of represented references within it, indicating its size and significance. The top 10 most relevant clusters are #0 optics (32 articles); #1 computer science, interdisciplinary applications (29 articles); #2 remote sensing (25 articles); #3 mathematics (24 articles); #4 engineering, electrical and electronic (19 articles); #5 automation and control systems (18 articles); #6 operations research and management science (17 articles); #7 robotics (16 articles); #8 engineering, multidisciplinary (14 articles); #9 engineering, manufacturing (13 articles) (Figure 4). Among these ten key areas, only a few are related to applied industries (engineering, electrical and electronic; engineering, manufacturing; remote sensing). At the same time, a more significant proportion of keywords are related to IT (computer science, robotics, automation and control systems, etc.), advancing this field. The review of the co-occurrence map of identified subject categories revealed two main disciplines connected with the point-cloud–NURBS relation, computer science and engineering, but not as independent disciplines but as part of multi- and interdisciplinary fields. The second layer that can be depicted from the results is sub-disciplines such as robotics, remote sensing, automation and control systems, and electronic and electrical engineering.

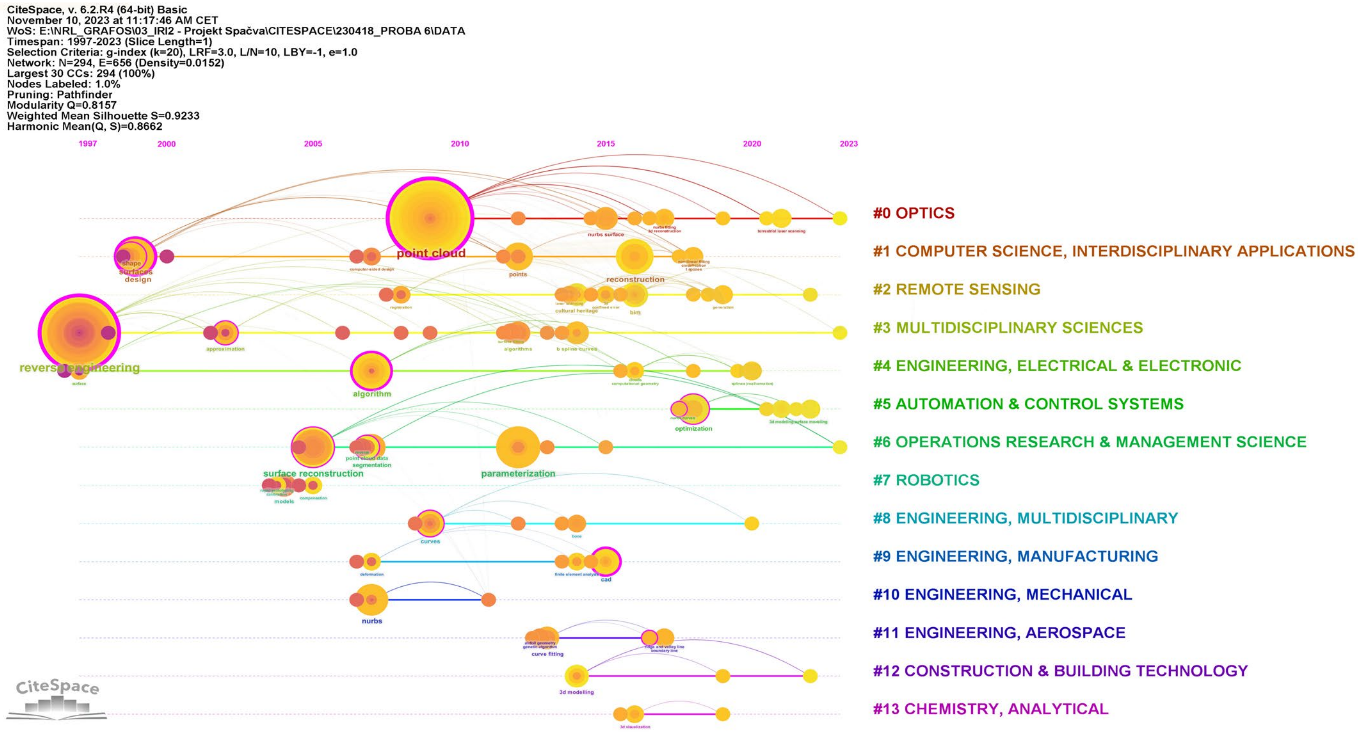

Figure 4. Network of co-occuring subject categories (CiteSpace 6.2.R4 software).

3.3. Network of Co-Occuring Keywords

Author Zhao (2017) defines keywords as representatives of the fundamental content of articles and indicators of the development of research topics over time [8]. He also states that in the WOS database, there are two types of keywords: (i) "author keywords" defined by authors and (ii) "keywords plus" identified by journals [8]. Two kinds of keywords were used for constructing the network of co−occuring keywords and their analysis. One hundred and forty articles were processed using software, resulting in a network of co−occuring keywords with 395 nodes and 1469 links. The node size represents the frequency with which the keyword appeared in the dataset. The top three high-frequency keywords are "point cloud" (frequency = 30), "reverse engineering" (frequency = 28), and "surface reconstruction" (frequency = 10) (Figure 5). The keyword "parametrisation" also has the same frequency (frequency = 10), followed by "design" (frequency = 8), "surfaces" (frequency = 7), "reconstruction" (frequency = 7), and algorithm (frequency = 7). The keyword "NURBS" appears several times (frequency = 6), while "optimisation" and "shape" have the same frequency of appearance (frequency = 5). Based on the results, the terms can be categorised into three key areas: the analysis of existing buildings, the design process, and the technology development.

According to citation bursts, 25 keywords were found (Burstness parameters: $f(x) = ae - x$, $a1/a0 = 2.0$, $ai/ai - 1 = 2.0$, The Number of States = 2, γ [0.1], Minimum Duration = 2, burst items found = 25). The top ten best-ranked keywords sorted by the Strengths of Burst are "design" (burst strength = 1.96, 2017–2021), "NURBS surface" (burst strength = 1.73, 2015–2016), "algorithms" (burst strength = 1.57, 2012–2014), "models" (burst strength = 1.51, 2004–2011), "non-uniform rational b-splines" (burst strength = 1.34, 1999–2000), "system" (burst strength = 1.28, 2004–2005), "rapid prototyping" (burst strength = 1.28, 2004–2005), "reverse" (burst strength = 1.25, 2007–2008), "3D modelling" (burst strength = 1.16, 2021–2023), and "bone" (burst strength = 1.16, 2014–2015). The mentioned terms represent popular topics (eng. hot topics) in the research on the point cloud and NURBS for the corresponding years. Through the clustering of keywords, it was possible to distinguish the main groups of terms associated with the predominant lines of research, such as (1) the point cloud, reverse engineering, and design; (2) algorithm and optimisation; and (3) surfaces and shape. Three stages of the complexity of keywords can be identified—the first group gathers the most complex constructs (technology and discipline), the second one involves processes that contribute to the quality of results, and the third one highlights basic constructs that build more complex results in the field. This result reveals hierarchical layers of studies that develop simultaneously and also the main scientific field—HBIM—as the head leader that gathers results from point-cloud–NURBS–BIM transformation. In summary, all three bibliometric results point to the simultaneous development of all levels of the field—from components that build point clouds, NURBS, and BIM, applied parts of the industry, to multidisciplinary areas handling the integration results of these three concepts. In terms of content, the review of author clustering, subject categories, and keywords clearly indicates the field of scanning existing buildings and surveys of historical architecture and heritage, showing the highest results in the field. The motivations for seeking the sequence from point cloud to BIM development, enhancement, and improvement are reducing time and manual work, increasing model accuracy and precision, increasing data consistency for the entire model, and preparing the model for further processing. The area of architectural heritage is significant for the development of these technologies as a source of need and a multidisciplinary work area. It can be expected that in this field or because of this research and working field, all three levels of the connection point-cloud–NURBS–BIM will continue to develop with the aim of achieving higher data quality and clearer communication between collaborators and disciplines.

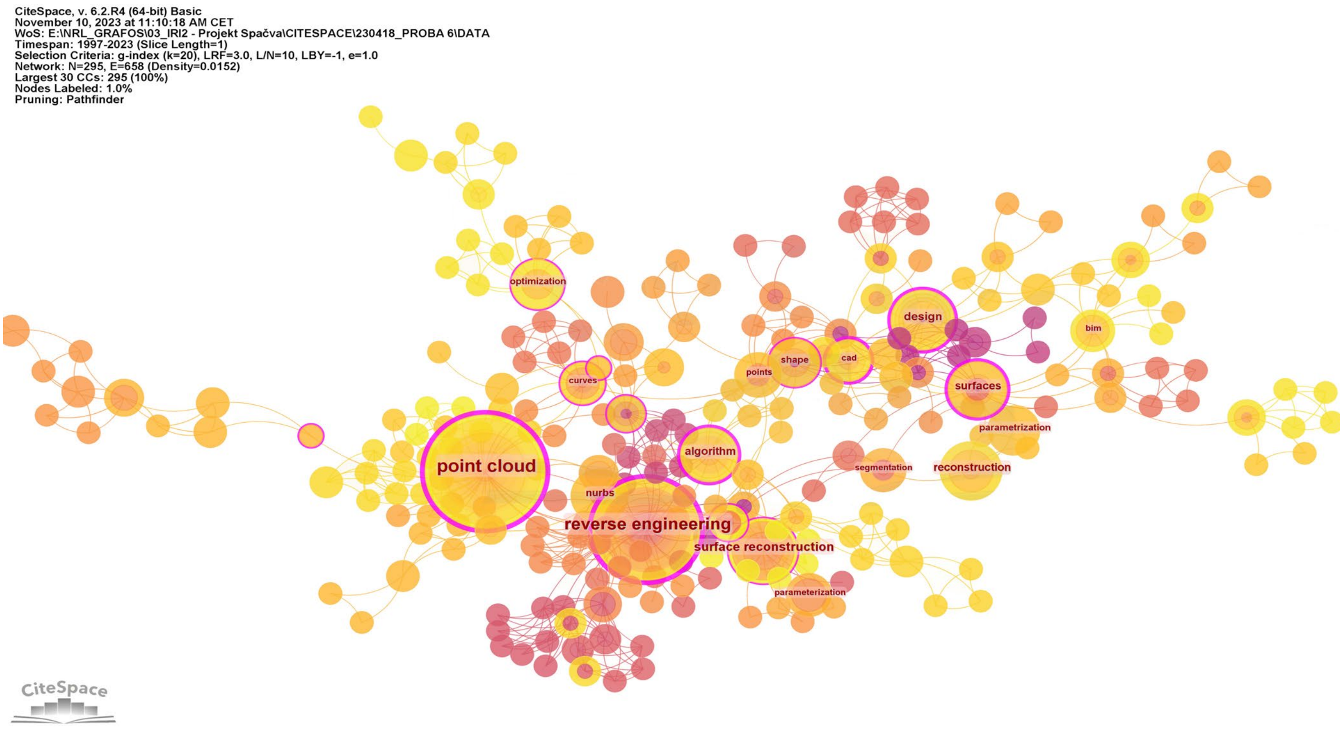

Figure 5. Network of co-occuring keywords (CiteSpace 6.2.R4 software).

3.4. Literature Connecting NURBS and BIM

Regarding the issues of BIM modelling, the literature derived from the keywords "NURBS" and "BIM" can be divided into two groups: scientific papers that use BIM modelling in the field of architectural heritage and papers that, regardless of the nature of the building, deal with process challenges, whether it is software tools, workflows, methods, approaches, schemes, frameworks, etc. The reviewed literature has grouped content according to identified problems and solutions mentioned in the papers.

3.4.1. Thematic Classification of Papers According to Highlighted Problems

One of the common goals of the literature review is to identify the main challenges in data transfer for creating detailed BIM. Data collected by point-cloud technologies in the first step are at risk of losing qualitative data in the transfer to NURBS. In the second step, the data are additionally lost or changed, and it is necessary to ensure the possibility of interpreting the model in the concept of parameterisation. This set of objectives presents technological and procedural challenges; specifically, a high level of detail, parametricity of model components, and model integrity are expected. Diara et al. (2019) introduced the term "anastylosis for shape affinity" to describe NURBS in BIM [24].

A smaller number of articles focus on individual topics. In comparison, a more significant number of works address combined topics due to the logical sequence of data transformation to the phase of their use as information. Three key issues in model building, interoperability, and automation have their respective issues that identify the root causes of the problems (Table 1).

Table 1. Categorisation of problems in NURBS to BIM technology transfer.

Problem	Problem Issue	Authors	References
model building	laser scan data	Radanović et al. (2020), Barazzetti et al. (2015)	[47,48]
	object libraries	Barazzetti et al. (2015), Barazzetti (2016), Banfi et al., (2018), Diara et al. (2019), Radanović et al. (2020), Argiolas et al. (2019)	[12,23,24,38,47]
	as-built model	Barazzetti (2016), Radanović et al. (2020), Qiu et al. (2021), Rausch et al. (2021), Gao et al. (2015), Werbrouck et al. (2020), Kim et al. (2021)	[38,47,49–53]
	semantic dimension	Barazzetti et al. (2016), Diara et al. (2019), Radanović et al. (2020), Qiu et al. (2021), Rausch et al. (2021), Abd Elwahab et al. (2019)	[22,24,47,49,50,54]
interoperability	data transfer	Barazzetti (2016), Silva et al. (2019), Miller et Stasiuk (2017), Qiu et al. (2021), Zhou et al. (2019), Banfi et al. (2017)	[38,49,55–58]
	disciplines	Barazzetti et al. (2016), Rahmani et al. (2015), Miller et Stasiuk (2017)	[22,56,59]
automatization	from point cloud to parametrised object, transfer to model for diagnostic	Banfi et al. (2017, 2018), Radanović et al. (2020), Perez-Perez (2021), Bruno et al. (2018), Argiolas et al. (2019), Barazzetti (2016), Rausch et al. (2021), Rahmani et al. (2015), Kim et al. (2021), Sharif et al. (2022), Abd Elwahab et al. (2019)	[12,22,23,47,50,53,54,59–62]

The problems in the field can be viewed as those arising from (1) data input—model building, (2) data exchange—interoperability, and (3) data processing—automation.

(1) The deficiency of methods attempting to reconstruct models through the direct interpolation of point clouds or NURBS in BIM software is emphasised by a group of authors [12,22–24,38,48,53,57] according to Table 1. Such methods cannot produce BIM models because BIM requires object-oriented elements for parametric design (Figure 5). No specialised software or universally accepted guidelines for scan-to-BIM processes make it challenging to categorise the modelling approaches for such objects [47]. Barazzetti et al. (2015) focus on developing a reconstruction methodology that preserves the level of detail in point clouds obtained through photogrammetric data collection and laser scanning [48]. They provide a method for creating BIM models of non-residential buildings, such as a complex medieval bridge [38]. Models generated in 3D modelling software that are not BIM-licensed typically lack parametric modelling tools and object-to-object relationships. The same issue arises when reconstructing the exact external form obtained through laser scanning and photogrammetry technologies. The original modelling tools provided in BIM software

do not offer options for developing complex surfaces, often resulting in partially or entirely non-parametric objects that require deep interventions and modifications. BIM models must include additional information about material properties, construction organisation, and more besides their external appearance. Therefore, there is a need for NURBS algorithms as a bridge to BIM models, and authors draw attention to the lack of advanced tools for creating models with NURBS interpolations in a parametric BIM platform [12]. Although BIM packages contain native tools for NURBS modelling, they usually offer only basic algorithms, which are not user-friendly. Therefore, most designers use other environments for direct 3D modelling [38]. In non-BIM applications, automatic algorithms cannot recognise and separate different constructive elements [38,55]. The insufficient software for working with irregular, complex-shaped architectural features and the inability to rely on standardised library objects are cited as common problems in BIM applications. These issues include the inability to accurately model irregular elements, handle complex shapes, and create highly detailed models, especially those related to cultural heritage [38,49]. Existing object libraries in BIM are mainly used for designing new buildings, and there is a shortage of advanced software algorithms for converting point clouds into parametric objects, particularly for irregular elements with no predefined shape. When representing the geometry of complex buildings, especially cultural heritage structures, parametric BIM objects have limitations [12,24,47]. Representing heritage buildings with high precision is challenging, and parametric BIM models tend to be superficial and imprecise. Generating as-built BIM models is another challenge highlighted by various author groups [38,47,49–52]. Capturing, interpreting, and representing existing conditions in a comprehensive BIM workflow are problematic. Using existing drawings, including 2D CAD, for generating as-built BIM models has proven to be primarily unreliable, especially in variations during construction. Precise data collection or monitoring is required to determine the actual form of built structures, which may differ from the design due to local anomalies, degradation, and various damages [38,52]. Creating as-built models is generally time-consuming and prone to errors due to the manual process, and the fully automatic generation of accurate BIM models is still in its early stages. One of the main challenges in creating as-built BIM is the manual selection of parameters that need parametrisation [38].

(2) Rahmani et al. (2015) aimed to achieve interoperability between software for various purposes, including BIM, energy and lighting simulations, and optimisation [59]. In their interoperability study, they intended to use an API visual programming environment that contributes to the existing interoperability study in which IFC and gbXML and their related APIs have a significant impact. Miller and Stasiuk (2017) wanted to improve interoperability between proprietary and production software and developed a methodology that uses different API interfaces and open-source tools to address interoperability issues for complex geometries in BIM [56]. Qiu et al. (2021) conducted the first study to explore the interoperability of BIM geometric data at the element level from the sketch to project [49].

(3) Within BIM platforms, poor workflow automation is one of the problems pointed out by author groups [11,47,53,58,59]. Radanovic et al. (2020) believe that the low level of automation in parametric modelling is closely linked to the non-recognition of objects and features in 3D [47]. When creating as-built models, precise modelling of all building elements still relies on user intervention [47]. Patraucen et al. (2015) note the increasing interest from industrial, academic, and political stakeholders in BIM modelling for automatic model generation due to the expected economic impact [7]. Perez-Perez (2021) focuses on automating 3D model generation from point cloud data, with a critical point being point cloud segmentation based on appearance and geometric properties [60]. Bruno et al. (2018) highlight the potential of BIM modelling in renovation processes to overcome critical issues arising during modelling and revitalising existing objects, provided the entire process is linked to cognitive

automation [61]. Connecting the BIM concept with automated systems enables increased control during project work phases and labour savings for quick interventions. One of the problems highlighted in the reviewed works is achieving geometrically exact models enriched with critical semantic information. Some works deal with the role of semantic data in addressing issues related to modelling, interoperability, and automation [11,22,47,50,53,54,58]. Rausch et al. (2021) emphasise the need to preserve critical semantic information in the initial BIM when generating the final as-built BIM [50]. Radanovic et al. (2020) aimed to re-evaluate existing modelling approaches, such as parametric and reality-based modelling, regarding generated models' geometric accuracy and semantic richness [47]. They aimed to enable the efficient creation of models with semantic richness and high geometric precision. Barazzetti et al. (2016) mention the goal of creating a database that includes semantics and object properties for generating and managing meaningful construction information [22]. Diara et al. (2019) aimed for precisely planned models, especially for classifying and defining their historical features related to the information system, where information and semantic dimensions are crucial [24]. They aimed to establish an information system for existing buildings with precautions for defining and classifying specific surfaces, workpieces, architectural components, and material databases. Banfi et al. (2017) aimed to transmit appropriate information (material authenticity) and the actual representation (geometric uniqueness) of the existing object, as well as its morphological and typological characteristics [58].

3.4.2. Thematic Classification of Papers Based on Proposed Solutions

The solutions presented by the authors are highly significant for developing this field and should be closely monitored. Six proposals for addressing modelling, interoperability, and automation issues have emerged from the reviewed papers' content as presented in Table 2.

Table 2. Categorisation of problem solutions in NURBS to BIM technology transfer.

Solution	Description	References
multi-LOD	Multi-LOD is based on the concept of defining design parameters, mostly geometrical, with uncertainty in the beginning and, at each level of development, with the aim of making the model more efficient	[12,24,38]
model in multi-format compilation of formats	Multi-format model is structured with geometrical and non-geometrical information while every kind of information can be integrated and presented in different format	[47,53]
locally modelled part of the building	In correspondence with multi-LOD and multi-format models; if the task is limited to the part of the building, the team can decide to model only part of the building or to raise the LOD for the part of the building	[23,58,63]
semantic bridge	A BIM semantic bridge is an interface platform between the BIM database of the model environment (3D representation) and the knowledge base represented by ontologies	[60]
plugin or additional software	It refers to a software component that adds specific features or functionality to a larger software application to enhance its capabilities. It depends on native software	[12,24,54,56,58,59]
proto-BIM, BIM sketch	A dynamically imagined model that enables tracking of all the changes and decisions from the first sketches until the final model	[49,50]

Diara et al. (2019) used NURBS models to create high-quality and detailed 3D models, which must be parametrised for further use within BIM platforms [24]. Each model is based on accurate measurements and can be interpreted and approximated according to the level of detail (LOD). Banfi et al. (2017) also used NURBS in developing a method for processing and creating complex parametric BIM models with multiple levels of detail (Mixed and Reverse LOD) based on precise photogrammetry and laser scanning research [58]. Their research emphasises the potential integration of NURBS for reducing time and costs in the Historic Building Information Modelling (HBIM) process [12]. Fregonese et al. (2017) highlight how using NURBS mathematical functions for creating 3D models allows for a higher degree of realism and more navigable and usable model dimensions, where only the most sculptural parts are replaced with mesh models [63]. In a study that re-evaluates existing approaches to heritage building modelling, Radanović et al. (2020) propose a new modelling concept based on a platform that uses a layered structure—integrated and interconnected layers can include various data and models, such as polygonal textured mesh models, point clouds, and parametric BIM models [47].

Due to the lack of library objects, Diara et al. (2019) required the development of specific 3D objects using advanced modelling tools (AMTs) based on different types of data, such as historical documentation and georeferenced data [24]. In further research, Banfi et al. (2017) aimed to generate 3D models of existing objects using unique 3D elements with all their specifics without grouping them into simplified architectural databases like libraries and families [58].

For example, some authors present algorithmic modelling, which allows the modelling of similar objects by reusing algorithms with modified input parameters [20]. They propose the software identification of correspondences and discrepancies and correction of negative and positive NURBS shifts according to the point cloud. Additionally, in the workflow of historic BIM objects, they aim to achieve a genesis that is both parametric and allows multiple reuses. Qiu et al. (2021) introduce the concept of the BIM model sketch and state that, as an extension of the BIM model sketch, they expect data reuse in the project to improve efficiency [49]. For this reason, they want to abstract the reuse of building elements from the BIM model sketch to facilitate BIM design. They aim to ensure the consistency of BIM models from the sketch to project and enable the reuse of the BIM model sketch in the design phases by using element identification schemes and segmentation–aggregation strategies based on IFC specifications. Rausch et al. (2021) promote proto-BIM, which, through automatic updates or changes in the shapes and positions of BIM elements, reflects the conditions on the construction site [50]. Their goal is to achieve an initial BIM capable of parametrically adapting its geometry to as-built needs to improve geometric compliance estimation and the development of the final as-built BIM. With this new approach, they intend to transform BIM from original, primitive representations of building assemblies (proto-BIM) into intelligent, dynamic, and progressive graphics suitable for geometric mediation.

Banfi et al. (2017) aimed to demonstrate how the method presented in their work can reduce time and costs and improve automation in the modelling process [58]. In their later work, they sought to achieve an automatic verification system (AVS) for the deviation values between the precise point cloud and the 3D object to contribute to accurate model generation [12]. Argiolas et al. (2019) set the goal of an automated workflow for the geometric modelling process of 3D laser data in situations where local modelling is required [19]. Barazzetti (2016) wanted to achieve a variable level of detail reconstruction based on NURBS, depending on the set of registered point clouds, which can be used following an automated strategy that ends when numerical accuracy is reached [38]. Rausch et al. (2021) propose automated geometric conformity methods aimed at developing specialised algorithms that isolate and analyse discrete geometric features [50]. They intended to enable BIM to automatically fit into 3D point cloud data by transforming the shapes and poses of BIM elements. Rahmani et al. (2015) suggest utilising and integrating advanced modelling and simulation technologies [59]. Kim et al. (2021) saw a solution in an automated method for generating as-built models with the complete extraction of geometric information, using the connectivity between building elements in point cloud data with incomplete information [49]. They emphasise the need for an automated method to model all aspects despite potential data deficiencies in the point cloud. Sharif et al. (2022) present a new framework for classifying and calculating final points based on automatic 3D scanning measurements and visualisations [62]. Abd Elwahab et al. (2019) aimed to automate the modelling process with a new plug-in using parametric modelling techniques [54], while Perez-Perez et al. (2021) propose an automatic scan-to-BIM process that uses point cloud geometric features to assign semantic labels to construction, architectural, and MEP components located nearby in point clouds common in commercial and industrial building projects [60]. Perez-Perez et al. (2021) set the goal of a Markov Random Field (MRF)-based learning method that assigns semantic labels to point cloud segments, with MRF contributing to the coherence between semantics and geometric labels and using neighbouring context for better semantic labelling [60].

4. Conclusions

The paper provides an overview of the field that shows data transformation from point clouds to BIM indirectly through NURBS. In the first part of this paper, works are bibliometrically analysed for the area that has been developing over the past 25 years, and specific knowledge has accumulated and directed the dynamics of further development. This research examines the direction in which a particular innovation is developing, verifies the development directions, and qualitatively assesses the areas in which concepts are developing. The papers reviewed in this first part indicate that data transformation from point clouds to NURBS is developing in a dispersed technical area. The application of this technology can be found in several industries, including archaeology, metallurgy, geodesy, and others. Still, the most extensive development is in the segments of technology (AI, mathematics, information systems, algorithms, and similar). Such results can guide us in addressing the issues in applying the technology in another area.

The works are reviewed in the second part of this paper by analysing their content and seeking problems for the transformation from NURBS to BIM and the solutions achieved in the works. The review of the papers revealed the uniqueness of the issues closely related to parametric modelling and insufficient automation in the BIM creation process. The segmented development of point clouds; mathematical, non-applicative development of NURBS; and development of the BIM concept for the highest market potential, new buildings, have resulted in gaps in data transformation for HBIM and projects with high accuracy and complexity. The overlay of the first results, in which the terms "reverse engineering" and "reconstruction" ranked high in the hierarchy of crucial concepts connecting point clouds and NURBS, with other results highlights the problem of high accuracy, low automation, and weak semantics, and points to the field of heritage BIM, as-built BIM, and scan-to-BIM, which strongly require solutions for the highlighted problems. Initiatives in data transformation come from designing new buildings, and solutions are sought immediately as part of technology development. The area that uses the developed technology has identified problems and is looking for answers. Solutions such as mixed models, multi-layered models, a mix of formats, or bridging elements (semantics, proto-model) are proposed. Finally, solutions, software, or mobile device applications are sought that will increase the accessibility of this technology, be more intuitive, and accelerate and popularise the positive aspects of BIM for broader applications.

However, the most important contribution of this study is the identification of bottlenecks and propulsive solutions in workflow from the point cloud via NURBS to BIM in different research fields. Engaging quantitative methods, such as a bibliometric study and network analysis, key problems and challenges in the review of publications about data transformation were identified. A list of common trends, layers of research, and focuses of research were outlined to consider when searching for lessons learnt. Results are based on bibliometric techniques, and the study of network metrics and systematic reviews. The most relevant knowledge that deals with data transformation arises in multidisciplinary fields, engaging computer science and different engineering fields while overspilling to reverse engineering, surface reconstruction, CNC engineering, and, highlighted by most of the analysis, historical and heritage building modelling. A further step was a systematic analysis of the literature for the second workflow step, the integration of NURBS to BIM that confirmed the same subject categories and research fields. A systematic literature analysis revealed the main problems and solutions we listed, described, and discussed. These findings are contributions of knowledge to the broad field that uses selected technologies (point cloud, NURBS, BIM). However, there are no major contributions that allow the identification of a measurable relationship or range of problems and solutions. Detected relations are based on the documented findings of various authors in an extensive base of scientific publications that could be further expanded with additional scientific databases (Scopus, Google Scholar, etc.) but also with grey literature rooted in the industry, such as industry reports and know-how technology transfer reports. This study may be a foundation for further development in this area, which opens opportunities for future lines of research.

4.1. Limitations of the Work

This research engaged mixed methodology involving a bibliometric and systematic review of identified literature. The first limitation to be stated is the limited amount of articles included in this research. The Web of Science Core Collection was used as a database while the biggest pool of articles was identified in this database. Limitations of the bibliometric analysis can be found in static results. Clusters and networks are presented without dynamic trends that reveal the character of the relationship between clusters, authors, and networks, so results are presented around intersecting researchers and constructs. Further and detailed insight into the time sequence and authors' relations should be studied more in detail to depict the flow of the ideas and solutions. The third limitation is a systematic analysis that could be at risk of bias in interpreting results. However, the presented results follow the consensus that arises from the reviewed literature that includes challenges in integrating, exchanging, and providing efficiency of data in point cloud, NURBS, and BIM workflow.

4.2. Future Studies

At first, future studies are motivated to avoid the limitations of the presented work. Therefore, with the aim to broaden and deepen study in further research, other sources and databases should be included, not only databases that provide scientific results but also industry reports, and know-how technology transformation. A broadened initial database should also be used for the identification and typology categorisation of good examples (see [64] that could give more clear answers to challenges and problems). A detailed review of the connection between the roots of problems and implemented out-of-the-box solutions would be a potential future challenge that could tackle raising interest in the field.

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