Discovering the Global Landscape of 3D Animation: A Bibliometric Analysis

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Abstract—The purpose of this study is to conduct a bibliometric analysis of publications on 3D animation in the Scopus database. Microsoft Excel, VOSviewer for data visualisation, and Harzing's Publish or Perish for citation metrics and analysis were employed to conduct the bibliometric analysis. Data were analysed among a sample of 305 publications on 3D animation published between 1984 and 2021 available in the Scopus database. The bibliometric analysis reveals that the number of publications on 3D animation research has been constantly increasing since 2002. In 2020, the total number of documents published in 3D animation reached 29 articles. China was named the most active country in the field of 3D animation. A total of 888 researchers from 43 different countries and 31 different institutions published 3D animations in multiple languages, including multi-author collaboration. Computer Science and Engineering are the two disciplines that are most prominently represented in the study of 3D animation. The most active institutions that published key publications linked to 3D animation research were Universitas Diponegoro and the University of Sharjah. This research is unique and significant to contribute to advancing the body of knowledge on 3D animation to add value to the complexities of scientific narratives. Future research direction is also furnished.

Keywords—3D animation, bibliometric analysis, VOSviewer, Harzing's Publish or Perish, Scopus database

1 Introduction

Current technology advancement, including Three-Dimensional (3D) animation has vastly improved life quality as it brings cartoon characters, props, vehicles, and other objects to life for usage in films, television shows, and video games through the use of motion. North America continues to dominate the 3D animation market [1]. The presence of important digital industry giants such as Fox, Nickelodeon, and Disney is one of the primary drivers of the 3D animation market's growth. Given the potential for 3D animation content generation, when the COVID-19 epidemic hit, almost 2.7 billion gamers generated over US$300 billion [2]. Within the Malaysian setting,

animation income from video games is expected to exceed US$402 million by 2021, with over 100 local companies have generated more than 20 distinct intellectual assets and exporting their work to more than 120 countries for a total of RM132 million [3].

Digital learning objects and/or digital simulation tools would promote learning activities and educational reform if they were effectively managed and used in conjunction with educational technology [4–7]. These scholars also stressed that the effects of digital technology on education should be measurable to motivate and engage students and lessons learned. Despite its immense potential for the animation business, 3D animation has gotten little public attention. This has necessitated greater study to enhance the existing literature. Given the significance of 3D animation in educational technology, it is critical to track its research developments. This research aims to bibliometrically analyse 3D animation papers in the Scopus database. Thus, the 3D animation analysis highlights are presented with suggestions for further study.

The rest of this paper is organised as follows. Section 2 reviews related literature, while Section 3 presents the methods that were employed. Section 4 describes the analysis of data. The last portion provides a conclusion as well as recommendations for further study.

2 Literature review

Animation is associated with cross-disciplinary and inter-disciplinary art and craft, including drawing, sculpture, model creation, performance, dance, computer science, social science, and many other disciplines [8]. 3D animation technologies create a virtual scene with overlaid spatial and temporal constraints due to their ease of use, dependability, and adaptability [8–9]. This characteristic aids in the digitalisation of traditions and culture, which has resulted in technological breakthroughs that have profoundly revolutionised the world of animation. The Anim8or programme uses 3D animations to help students master algebraic and calculus functions as well as a variety of valuable computing skills [10]. The Go Animate 4 Schools website allows students to test their skills in developing slide shows to visually describe concepts and connect efficiently with their audience [11].

Animators must go through numerous stages of modelling, rigging, and animation in order to generate a 3D animation [12]. Plus, they are significantly involved in several early stages of visual effects production to guarantee they supply the appropriate content for real-world model animation. Additionally, the aspect of character movement, a type of artistic expression in 3D animation that combines aesthetic expression and technical execution, is also important in 3D animation [13]. A gesture-based natural user interface is preferred over a cursor-based interface for controlling a 3D animation, resulting in a more engaging and delightful user experience [14]. Indeed, many films and television shows employ 3D animation special effects technology to replace actual scene lenses and create more realistic special effects photos, reducing the risk of damage to actors and improving the picture quality [15–16]. They choose an effect map from the computer's library, build the virtual picture, set up a virtual camera, and lastly, place the virtual light on the scene to ensure the final visual effects are impressive. Table 1 details the five main roles of 3D animation special effects [16].

Table 1. The main role of 3D animation special effects

3D Animation	Main Role
Visual effect	In the process of in the first place, to make up for the lack of pictures.
Shadow effects	The most expressive special effects that regulate the lighting values in virtual images.
Lens conversion effects	Multi-angle conversion of the lens.
Interactive effects	Make the characters in the animation combine with the environment, so that the characters in the correct environment express the correct form of action.
Interactive effects	In the process of special effects production is very important, adding the overall authenticity, dynamic and three- dimensional sense.

Source: Li [16].

3 Methods

This study used bibliometric, quantitative, and statistical methods to characterise research publication distribution trends within defined themes and time periods [17]. The bibliometric analysis has been utilised extensively in business studies, including business strategy [18], electronic commerce [19], finance [20], human resources [21], management [22], and marketing [23] for assessing an existing subject's intellectual structure and tracking article and journal performance trends, and research features [24–25]. This research used data from the Scopus database, the world's largest collection of academic literature, which has the most citations and abstract sources. Precisely, the TITLE was queried for 305 entries containing the phrase "3D animation." The search was carried out on September 30, 2021. The research's structure is established by social network analysis tools (see Figure 1). The key themes of the research field are then determined. The Scopus database has been acknowledged to contain more comprehensive sources for fields than the Web of Science [26–27]. The VOSviewer and Perish or Publish software tools were used to analyse a sample of 305 studies. VOSviewer is a handy tool for visualising bibliometric networks by calculating the distance between two nodes, which reveals their relatedness [28].

4 Results

This section presents the findings of a bibliometric study of research publications on 3D animation extracted from the Scopus database. The analysis yields information about the document types, publication years, and subject area. Additionally, bibliometric statistics on the countries with the most publications, the most prestigious publishing venues, the most prominent institutions, keyword analysis, and citation analysis are included.

4.1 Document and source types

Table 2 details that more than half of the documents (66.89%) are conference papers, followed by articles (30.49%) and reviews (1.64%).

Table 2. Document type

Document Type	Total Publications (TP)	Percentage (%)
Conference Paper	204	66.89
Article	93	30.49
Review	5	1.64
Book Chapter	2	0.66
Short Survey	1	0.33

4.2 Year of publications

The growth of published research on 3D animation between 1984 and 2021 is illustrated in Table 3. The year 2020 saw the most publications, totalling 29 documents with 11 total citations. This is followed by 22 total publications in 2017 as the second-highest total of publications, totalling 47 total citations. The period from 1984 to 1999 has the fewest publications, with a total of less than five.

Table 3. Year of publication

Year	TP	NCP	TC	C/P	C/CP	*h*	*g*
2012	10	11.11	100	10.00	2.80	3	10
2013	18	7.13	57	3.17	3.06	3	7
2014	13	8.14	57	4.38	2.62	3	7
2015	9	8.67	52	5.78	4.56	3	7
2016	12	6.60	33	2.75	2.92	3	3
2017	22	11.75	47	2.14	2.59	4	6
2018	12	5.33	16	1.33	2.58	2	3
2019	14	11.50	23	1.64	3.50	3	4
2020	29	11.00	11	0.38	2.76	2	2
2021	17	3.00	3	0.18	2.47	1	1

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; *h* = h-index; and *g* = g-index.

4.3 Subject area

Table 4 summarises the subject categories of which Computer Science is the most heavily represented discipline in 3D animation studies (65.57%), followed by Engineering (34.43%), Social Sciences (12.13%), Mathematics (10.82%), Physics and Astronomy (6.56%), and Arts and Humanities (3.28%), all of which contribute to the

overall number of articles on 3D animation. As a result, Computer Science and Engineering are the two disciplines that are most prominently represented in the study of 3D animation.

Table 4. Subject area

Subject Area	Total Publications (TP)	Percentage (%)
Computer Science	200	65.57
Engineering	105	34.43
Social Sciences	37	12.13
Mathematics	33	10.82
Physics and Astronomy	20	6.56

4.4 Most active source titles

Table 5 lists the top five publishing outlets with the most active source titles producing 3D animation articles. "Lecture Notes in Computer Science, Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics" and "Journal of Physics Conference Series" have ten published works between them.

Table 5. Top five active publishing

Source Title	Total Publications (TP)	Percentage (%)
Journal of Physics Conference Series	10	3.28
Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	10	3.28
Advances in Intelligent Systems and Computing	8	2.62
Advanced Materials Research	6	1.97
ACM International Conference Proceeding Series	4	1.31

4.5 Keywords analysis

Figure 2 depicts a network visualisation map to aid in the comprehension of the keyword analysis for 3D animation. Important research fields and tools were derived from these keywords using VOSviewer. Cluster differentiation was accomplished by connecting the co-occurrence representations of the two terms and determining the colour and size of the circles. The relative size of the typeface indicates the relative popularity of the terms [29]. Animation, Three-Dimensional Computer Graphics, Three-Dimensional Virtual Reality, Algorithms, Teaching, User Interfaces, Computer Graphics, and Visualisation are all terms that are frequently used in conjunction with aspects of 3D animation. There are six clusters, and a minimum of five occurrences are used, which led to generating 76 items from the VOSviewer. Cluster 1, in red, includes education, multimedia, articles, human resources, real-time systems, signal processing, and geometry.

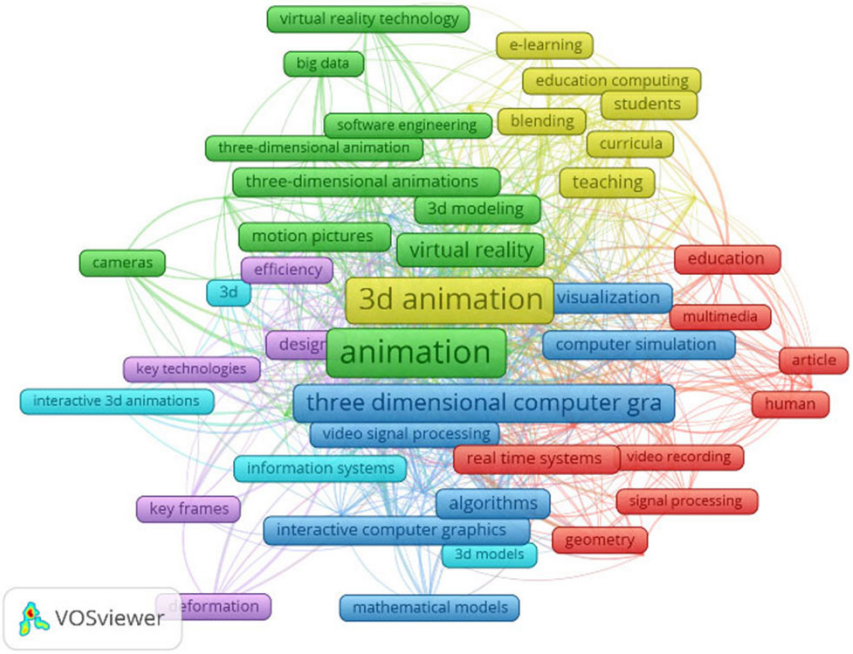

Fig. 2. All keywords dispersed in network visualisation map from 1984 to 2021

Cluster 2, in green, consists of animation, virtual reality, motion pictures, cameras, 3D animation, software engineering, big data, and virtual reality technology. The blue colour depicts the third cluster as interactive computer graphics, algorithms, mathematical models, user interfaces, three-dimensional computer graphics, computer simulations, and visualisation. Next, cluster four in yellow includes 3D animation, teaching, curricular, students, education computing, blending, and e-learning. Cluster 5 in purple consists of key frames, key technologies, deformation, design efficiency, and information technology. Lastly, the sixth cluster, in light blue, includes 3D, 3D models, interactive 3D animations, and information systems. Curating network clusters and tracking their evolution can aid in comprehending how a research topic emerges and evolves.

4.6 Geographical distribution of publications

Individual countries' research production indices for 3D animation are calculated based on the geographical distribution of publications. Table 6 evidences the volume of publications on 3D animation produced by each country. China is one of the top countries for 3D animation, with 80 publications (26.23%) out of a total of 305 publications. The United States is rated second, with 55 publications (18.03%). Taiwan, on the other hand, ranks third with 21 publications (6.89%).

Table 6. Top 10 countries contributed to the publications

Country	Total Publications	%	Country	Total Publications	%
China	80	26.23	United Kingdom	17	5.57
United States	55	18.03	Indonesia	15	4.92
Taiwan	21	6.89	Malaysia	10	3.28
Japan	20	6.56	France	9	2.95
South Korea	17	5.57	India	9	2.95

4.7 Authorship

The most productive authors are Ahmed from the University of Sharjah in the United Arab Emirates and Ariyanto from Universitas Diponegoro in Semarang, Indonesia (see Table 7). In terms of productivity, eight of the top ten authors published more than four documents, while the remaining authors published fewer than four.

Table 7. Most productive authors

Author's Name	Total Publications (TP)	Percentage (%)
Ahmed, N.	6	1.97
Ariyanto, M.	5	1.64
Caesarendra, W.	4	1.31
Furukawa, M.	4	1.31
Ismail, R.	4	1.31
Kawai, Y.	4	1.31
Kawasaki, H.	4	1.31
Tseng, J.L.	4	1.31
Akagi, Y.	3	0.98
Fukumoto, S.	3	0.98

4.8 Citation analysis

The total citations of the 305 documents was 1505, with citations per year of 40.68 and citations per author of 4.93 (see Table 8). The co-citation analysis of cited authors was performed for the period beginning in 1984 and ending in 2021.

Table 8. Citations metrics for 3D animation

Metrics	Data
Publication years	1984–2021
Citation years	37 (1984–2021)
Papers	305
Citations	1505
Citations/year	40.68
Citations/paper	4.93
Authors/paper	2.89
h-index	17

Figure 3 shows various different clusters of co-citation analysis of cited authors from 1984 to 2021. For the analysis, a threshold of a minimum number of five documents was set. Of the 305 documents, 60 meet the threshold. The findings reveal a slew of distinct clusters. Each subfield of 3D animation study is represented by a cluster or combination of clusters.

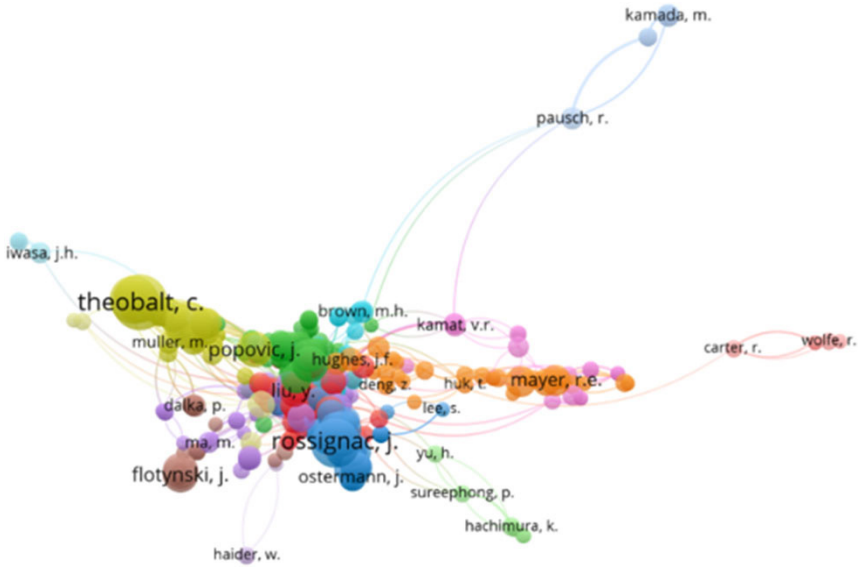

Fig. 3. Co-citation analysis of cited authors from 1984 to 2021

Table 9 contains the top ten most-cited publications. The work "Stylized rendering techniques for scalable real-time 3D animation" by Lake et al. [30] received the most citations (164 total citations). Besides, Ibarria and Rossignac's [31] article "Dynapack: Space-time compression of 3D animations of triangle meshes with fixed connectivity" received the second-most citations (130 total citations). This is followed by Briceno et al.'s [32] article "Geometry videos: A new representation for 3D animations," which has 119 total citations. Among et al.'s [33] work "3D puppetry: A Kinect-based interface for 3D animation" received 85 total citations in 2012.

Table 9. Top ten highly cited articles

No.	Authors (Year)	Title	Source	TC	C/Y
1	"A. Lake, C. Marshall, M. Harris, and M. Blackstein (2000)".	"Stylized rendering techniques for scalable real-time 3D animation".	"Proceedings First International Symposium on NonPhotorealistic Animation and Rendering".	164	7.81
2	"L. Ibarria, and J. Rossignac (2003)".	"Dynapack: Space-time compression of the 3D animations of triangle meshes with fixed connectivity".	"ACM SIGGRAPH/ Eurographics Symposium on Computer Animation, SCA 2003".	130	7.22
3	"H.M. Briceno, P.V. Sander, L. McMillan, S. Gortler, and H. Hoppe (2003)".	"Geometry videos: A new representation for 3D animations".	"ACM SIGGRAPH/ Eurographics Symposium on Computer Animation, SCA 2003".	119	6.61
4	"R.T. Held, A. Gupta, B. Curless, and M. Agrawala (2012)".	"3D puppetry: A Kinect-based interface for 3D animation".	"25th Annual ACM Symposium on User Interface Software and Technology, UIST 2012".	85	9.44
5	"R.C. Waters, D.B. Anderson, J.W. Barrus, D.C.Brogan,M.A.Casey, S.G. McKeown, T. Nitta, I.B. Sterns, and W.S. Yerazunis (1997)".	"Diamond Park and Spline: Social virtual reality with 3D animation, spoken interaction, and runtime extendability".	"Presence: Teleoperators and Virtual Environments".	55	2.29
6	"M. Bell, C. Dean, and M. Blake (2000)".	"Forecasting the pattern of urban growth with PUP: A web-based model interfaced with GIS and 3D animation".	"Computers, Environment and Urban Systems".	41	1.95
7	"T. Tung, T. Matsuyama (2010)".	"Dynamic surface matching by geodesic mapping for 3D animation transfer".	"IEEE Computer Society Conference on Computer Vision and Pattern Recognition, CVPR 2010".	40	3.64
8	"J. Lu, P.V. Sander, and A. Finkelstein (2010)".	"Interactive painterly stylisation of images, videos and 3D animations".	"ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games, I3D 2010".	36	3.27
9	"M. Ma, H. Zheng, and H. Lallie (2010)".	"Virtual reality and 3D animation in forensic visualization".	"Journal of Forensic Sciences".	33	3

(Continued)

Table 9. Top ten highly cited articles *(Continued)*

No.	Authors (Year)	Title	Source	TC	C/Y
10	"C.-F. Wu, and M.-C. Chiang (2013)".	"Effectiveness of applying 2D static depictions and 3D animations to orthographic views learning in graphical course".	"Computers and Education".	31	3.88

Notes: TC = Total citations; C/Y = Total citations per year.

5 Discussion

This study determined the evolution patterns in 3D animation between 1984 and 2021 through a bibliometric examination of the Scopus database and provided answers to four research questions. The year 2020 saw the most publications on 3D animation, with English as the most widely published language globally, followed by the Chinese language, and the conference proceedings were the primary source of publications. Indeed, China is one of the countries that contributed to the most publications on 3D animation. This research revealed that Computer Science and Engineering are the two disciplines that are most prominently represented in the study of 3D animation.

The two most important sources for 3D animation are "Lecture Notes in Computer Science, Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics", and "Journal of Physics Conference Series." The study identified keywords such as animation, 3D animation, Three-Dimensional Computer Graphics, and Three Dimensional in connection with frequently used terms for 3D animation. These results confirmed that 3D animation boosts one's interest and attention to images due to its reliability and versatility, and technological breakthroughs to generate a virtual scene with layered spatial and temporal limitations for more realistic special effects photos [8–9]. Indeed, the effective utilisation of educational technology, and gamification have enormous influence on student motivation and engagement tads learning [4–7]. Jia and Wang [15] share similar insights, which also echoes Li [16].

The work "Stylized rendering techniques for scalable real-time 3D animation" by Lake et al. [30] garnered the most citations. The study discusses real-time approaches to replicate cartoon styles and variants on texture mapping to accomplish real-time pencil drawing. The researchers include geometry in the cartoon scenario to emphasise the motion of cartoon objects. In order to provide real-time performance on every platform, the rendering system is combined with an animation system and a runtime multiresolution mesh system. These technologies enable non-photorealistic animation and rendering on low- to high-end consumer platforms by applying new technology to models created with common modelling tools.

The article "Dynapack: Space-time compression of the 3D animations of triangle meshes with fixed connectivity" written by Ibarria and Rossignac [31] obtained the second most citations. Dynapack reduces 3D animations of triangular meshes with continuous connectivity. Based on three of its neighbours in frame f and the previous frame, the study forecasts each vertex's position (space-time compression). The ELP

extension of the Lorenzo predictor and the Replica predictor are shown. The ELP predictor is helpful for translating sections of the animation. The Replica predictor predicts every combination of translation, rotation, and uniform scaling. Dynapack compression and decompression is simple and fast, accessing two frames at a time. It can decompress as well as compress real-time data.

Furthermore, it was discovered that Briceno et al. [32]'s scientific work "Geometry videos: A novel representation for 3D animations" was the third most-cited article. This article offers a method for creating animated geometry videos. It resamples and reorganises geometry data to give a consistent and straightforward technique for mesh resolution and frame rate adjustment. Their resource and computational needs can be estimated precisely, making them useful for applications demanding service level assurances.

6 Conclusion

In a nutshell, the results are noteworthy as they emphasise the importance of 3D animation, its underlying dynamics, and future research prospects. It contributes to the body of knowledge regarding 3D animation and its potential for enhancing the complexity of scientific narratives. Bibliometric analysis was used to document and analyse the expanding panorama of research that comprises this emerging knowledge base. The software packages MS Excel and VOSviewer were used to analyse bibliographic data exported from the Scopus database. The authors compiled a list of 305 research publications on 3D animation. The results provide empirical evidence on the scope and nature of 3D animation, as well as a critical examination of this new field of study and practice. This bibliometric analysis of publications on 3D animation has focused on providing answers to the following research questions:

RQ1 What is the current publication trend and influence in the field of 3D animation?
RQ2 Which countries, institutions, and writers have made the most contributions and are the most significant in the field of 3D animation?
RQ3 What are the most frequently encountered sources in 3D animation?
RQ4 What are the articles that had the biggest influence on 3D animation?

Due to the limits inherent in the field of 3D animation, the sample size obtained in this research is limited. Therefore, additional research is proposed to examine a larger number of documents for bibliometric analysis that include computer animation and digital animation with a broader view of digital content creation. Future studies are recommended to examine the chances for sustainable growth in the 3D animation content creation industry via the lens of virtual reality and gaming. The aspects of gaming [34], problem-based learning and digital games [35], and game-based learning kits with the integration of augmented reality [36] are also worth consideration in future research. By identifying developing patterns in the field and comparing them to earlier research on the subject of 3D animation, this study serves as a reference for future research. A better focus on culturally relevant, creative animation content in future studies would help the digital economy grow faster. There is a strong focus on the digitalisation of content, which is aided by improvements in technology that make it possible to create more immersive 3D worlds.

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