DIGITAL DESIGN IN ARCHITECTURE

RESEARCH LANDSCAPE MAP 1975–2019

with data from ~12,000 articles mapped & clustered by who cited who

The map is generated with data from the following publications:

1. 3D–Arch 2015 – 3D Virtual Reconstruction And Visualization Of Complex Architectures (63)
2. Automation In Construction (2273)
3. Architectural Design (1683)
4. AI EDAM–Artificial Intelligence For Engineering Design Analysis And Manufacturing (734)
5. Advances In Architectural Geometry 2016 (22)
6. ACADIA Conference Proceedings (118)
7. Computer–Aided Design (3168)
8. Computational Ecologies: Design In The Anthropocene (44)
9. CAADRIA Conference Proceedings (447)
10. CAAD Futures Conference Proceedings (33)
11. Design Studies (486)
12. Environment And Planning B–Planning & Design (2030)
13. eCAADe Conference Proceedings (731)
14. International Journal of Architectural Computing (85)
15. Mass Customisation And Personalisation In Architecture And Construction (17)
16. Nexus Network Journal (369)
17. Performance–Oriented Architecture: Rethinking Architectural Design And The Built Environment (7)
18. SimAUD Conference Proceedings (29)
19. TECHNE–Journal Of Technology For Architecture And Environment (233)

Data snapshot: 23 January 2019

The map is not the territory.
Alfred Korzybski

You can use this map to learn about the various concepts that build the field of digital design in architecture and the main authors defining them.

You can also check what is not there yet.

Is this map the absolute truth? NO!

The algorithms used to structure and plot the data are stochastic, i.e. each time you run them on the same data they will produce slightly varying results. Also, my selection of literature might not be the absolute definitive research body in this field. Furthermore, the cluster labels are generated from most common words and phrases, so important but less popular contributions might not have been acknowledged. Literature that is important might not have been associated with a cluster and, so too, remained unacknowledged on the map.

Nevertheless, the map gives an initial overview of the relationships between the various fields and can be a good starting point for more in-depth research.

And I hope it will trigger discussions in the digital and computational design community.

MAP

On the map, each point represents an article. The coordinates of each article depend on how close it is to other articles, measured by how similar are the lists with their cited articles and cited authors.

The research clusters marked in color are derived using an algorithm that groups the points based on their proximity to one another.

For each research cluster, I generated a label consisting of the number of articles associated with it, the most commonly occurring phrases and words in the titles and abstracts, as well as the most cited authors, and the most cited articles.

Since there are established three-word-terms such as *Building Information Modeling* in the field, it makes sense to look for the most common trigrams, as well as bigrams and single words. The list of top-cited authors reveals who defines and drives the research in each cluster. Such as *Christopher Alexander* being central to the *Theory of Planning* cluster. Finally, the list of most cited articles gives us the seminal works that everyone working in that field always refers to. For example, in the *Shape Grammars* cluster, we have the *The Palladian Grammar* by George Stiny and William J. Mitchell from 1978.

I used the algorithmically extracted info for each cluster to give it a title. Note that the titles are my interpretation. Let me know if you agree or disagree with them.

CLUSTER TREE

The tree chart below traces when did the algorithm found it necessary to split a group of articles into two. The sooner a cluster broke off of the main trunk, the more disconnected are the articles it contains from the rest of the research body.

My observation is that *Shape Grammars* is usually the first cluster to split from the bulk, which means it is the topic most distinguishable from every other topic in digital design in architecture. At least in terms of the features we use — cited authors and cited works.

It also makes sense to track the cluster with the early experiments in the field. It contains authors like William J. Mitchell and covers all the diverse case studies and hypotheses of what computers can bring into the field of architecture that had become the seeds for the other clusters. The *Early Experiments* cluster splits off relatively late, i.e. it builds the core of the tree's trunk.

In general, it is interesting to observe where things split from each other in this tree. If we take *Shape Grammars* out then what is the next most distinguishable field of research?

I couldn't figure out what's the deal with all the *Smiths* in the cluster I labeled *The Smith Glitch*. Maybe someone can help me solve this mystery.

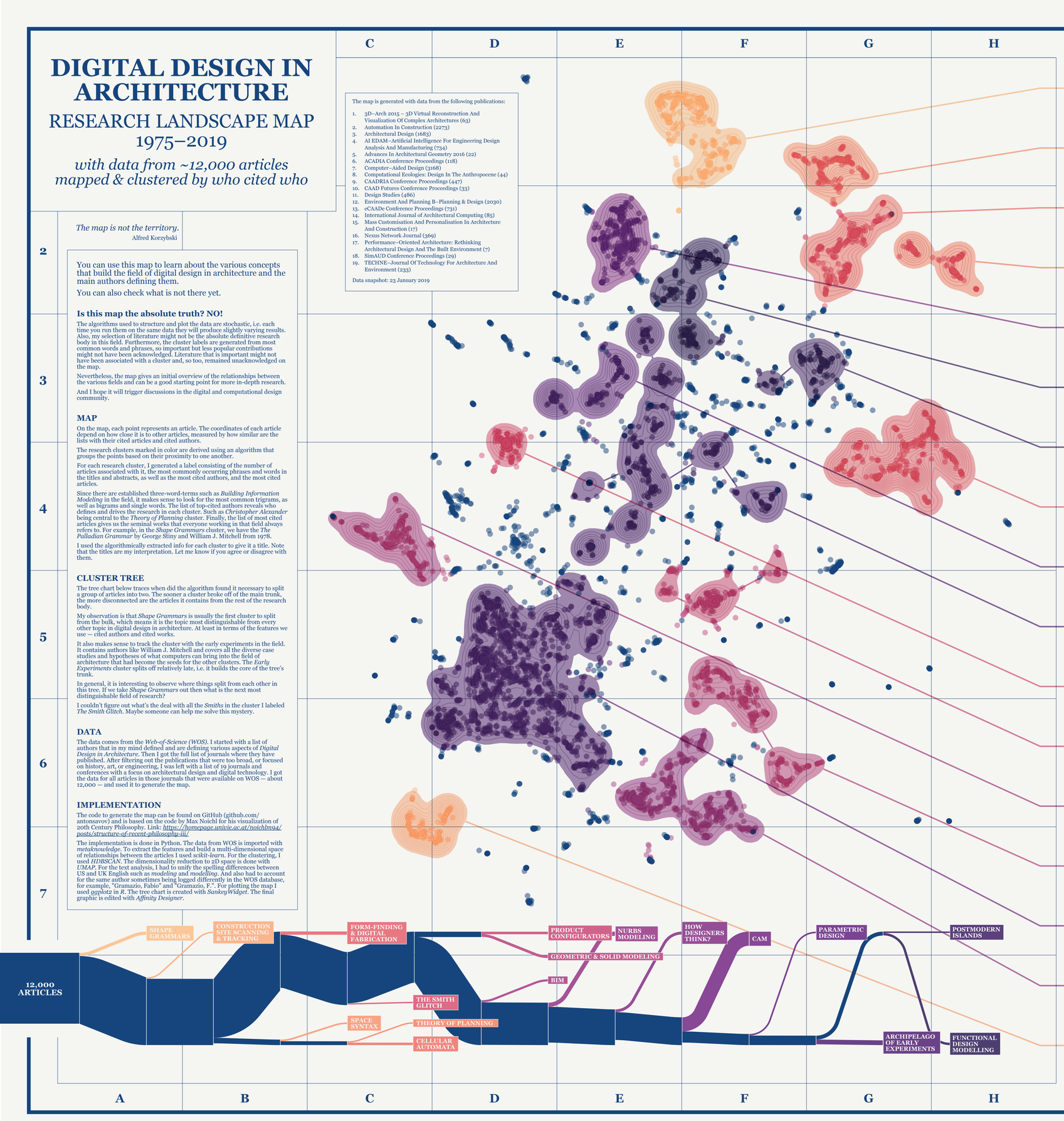
DATA

The data comes from the *Web-of-Science (WOS)*. I started with a list of authors that in my mind clearly and/or defining various aspects of *Digital Design in Architecture*. Then I got the full list of journals where they have published. After filtering out the publications that were too broad, or focused on history, art, or engineering, I was left with a list of 19 journals and conferences with a focus on architectural design and digital technology. I got the data for all articles in those journals that were available on WOS — about 12,000 — and used it to generate the map.

IMPLEMENTATION

The code to generate the map can be found on GitHub (github.com/antonsavov) and is based on the code by Max Noichl for his visualization of 20th Century Philosophy. Link: *https://homepage.univie.ac.at/noichlm94/posts/structure-of-recent-philosophy-ii/*

The implementation is done in Python. The data from WOS is imported with *metaknowledge*. To extract the features and build a multi-dimensional space of relationships between the articles I used *scikit-learn*. For the clustering, I used *HDBSCAN*. The dimensionality reduction to 2D space is done with *UMAP*. For the text analysis, I had to unify the spelling differences between US and UK English such as *modeling* and *modelling*. And also had to account for the same author sometimes being logged differently in the WOS database, for example, "Gramazio, Fabio" and "Gramazio, F.". For plotting the map I used *ggplot2* in *R*. The tree chart is created with *SankeyWidget*. The final graphic is edited with *Affinity Designer*.



CLUSTER TITLE	WORDS & PHRASES	MOST CITED AUTHORS	MOST CITED WORKS
SHAPE GRAMMARS 415 articles	shape grammars, rules, generation, systems, design process, architectural design, design space, language, plans, implementation, formal, layout, representation, computer, floor, urban	Stiny, G. (356x) Knight, T. (170x) Flemming, U. (110x) March, L. (104x) Mitchell, W. (91x) Duarte, J. (86x) Krishnamurti, R. (86x) Gero, J. (60x)	Stiny, G., & Mitchell, W. J. (1978). The Palladian Grammar | Stiny, G. (1980). Introduction to Shape and Shape Grammars | Koning, H., & Eizenberg, J. (1981). The Language of the Prairie: Frank Lloyd Wright's Prairie Houses | Stiny, G., & Gips, J. (1972). Shape grammars and the generative specification of painting and sculpture | Stiny, G. (2006). Shape: Talking about Seeing and Doing
SPACE SYNTAX 214 articles	space syntax, street network, spatial structure, urban design, spatial configuration, urban, patterns, movement, network, properties, measures, morphology	Hillier, B. (176x) Turner, A. (68x) Batty, M. (67x) Peponis, J. (65x) Benedikt, M. (56x) Lynch, K. (40x) Penn, A. (35x) Hanson, J. (32x)	Hillier, B., & Hanson, J. (2005). The social logic of space | Benedikt, M. L. (1979). To Take Hold of Space: Isovists and Isovist Fields | Turner, A., Doxa, M., O'Sullivan, D., & Penn, A. (2001). From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space | Hillier, B., Penn, A., Hanson, J., Grajewski, T., & Xu, J. (1993). Natural Movement: Or, Configuration and Attraction in Urban Pedestrian Movement | Hillier, B. (1996). Space is the machine: A configurational theory of architecture
CELLULAR AUTOMATA 322 articles	cellular automata, urban growth, landuse change, urban planning, urban design, planning support, land, city, systems, fractal, simulation, GIS, dynamics, agent	Batty, M. (243x) White, R. (75x) Couclelis, H. (57x) Clarke, K. (56x) Wu, F. (55x) Klosterman, R. (49x) Landis, J. (48x) Mandelbrot, B. (48x)	Clarke, K. C., Hoppen, S., & Gaydos, L. (1997). A Self-Modifying Cellular Automaton Model of Historical Urbanization in the San Francisco Bay Area | White, R., & Engelen, G. (1993). Cellular Automata and Fractal Urban Form: A Cellular Modelling Approach to the Evolution of Urban Land-Use Patterns | Batty, M., & Longley, P. (1994). Fractal cities: A geometry of form and function | Parker, D. C., Manson, S. M., Janssen, M. A., Hoffmann, M. J., & Deadman, P. (2003). Multi-agent systems for the simulation of land-use and land-cover change: A review | Couclelis, H. (1985). Cellular Worlds: A Framework for Modeling Micro—Macro Dynamics
THEORY OF PLANNING 175 articles	spatial planning, planning process, planning, urban, local, performance, public, practice, implementation, planners	Alexander, C. (62x) Alexander, E. (59x) Healey, P. (59x) Faludi, A. (49x) Forester, J. (44x) Innes, J. (41x) Friend, J. (34x) Friedmann, J. (29x)	Alexander, C. (1964). Notes on the synthesis of form | Forester, J. (1989). Planning in the face of power | Healey, P. (1996). The Communicative Turn in Planning Theory and its Implications for Spatial Strategy Formation | Alexander, E. R., & Faludi, A. (1989). Planning and Plan Implementation: Notes on Evaluation Criteria | Rittel, H., & Webber, M. (1973). Dilemmas in a general theory of planning
HOW DESIGNERS THINK? 372 articles	architectural design process, design thinking, knowledge, cognitive, problem, understanding, sketching, studies, practice, creative, collaborative, learning, teaching, tools	Schon, D. (259x) Cross, N. (232x) Lawson, B. (132x) Dorst, K. (117x) Goldschmidt, G. (116x) Gero, J. (102x) Simon, H. (101x) Goel, V. (79x)	Schon, D. (1984). The Reflective Practitioner: How Professionals Think In Action | Dorst, K. & Cross, N. (2001). Creativity in the design process: co-evolution of problem–solution | Goel, V. (1995). Sketches of thought | Cross, N. (2007). Designerly ways of knowing | Cross, N., Christiaans, H., & Dorst, K. (1996). Analysing design activity
FUNCTIONAL DESIGN MODELLING 312 articles	functional, knowledge-based, design process, conceptual design, engineering design, product, systems, representation, learning, planning, reasoning, urban	Gero, J. (124x) Pahl, G. (78x) Goel, A. (73x) Brown, D. (69x) Maher, M. (68x) Chandrasekaran, B. (57x) Umeda, Y. (56x) Stone, R. (54x)	Gero, J. S. (1990). Design Prototypes: A Knowledge Representation Schema for Design | Hirtz, J., Stone, R., McAdams, D., Szykman, S., & Wood, K. (2002). A functional basis for engineering design: Reconciling and evolving previous efforts | Stone, R., & Wood, K. (1999). Development of a Functional Basis for Design | Umeda, Y., Ishii, M., Yoshioka, M., Shimomura, Y., & Tomiyama, T. (1996). Supporting conceptual design based on the function-behavior-state modeler | Otto, K. N., & Wood, K. L. (2006). Product design: Techniques in reverse engineering and new product development.
POSTMODERN ISLANDS 175 articles	urban, planning, physical, systems, interactive, project, relationship, city	Jencks, C. (25x) Rossi, A. (22x) Tafuri, M. (22x) Harvey, D. (18x) Alberti, L. (16x) Rowe, C. (15x) Frampton, K. (14x) Banham, R. (12x)	Fox, M., & Kemp, M. (2009). Interactive architecture | Harvey, D. (1989). The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change | Graham, S., & Marvin, S. (1996). Telecommunications and the City: Electronic Spaces, Urban Places | Tafuri, M. (1976). Architecture and Utopia: Design and Capitalist Development | Rossi, A. (1995). L'architettura della citta
FORM-FINDING & DIGITAL FABRICATION 409 articles	digital fabrication, robotic fabrication, computational design, form-finding, material, construction, structure, performance, parametric, concrete, generative, physical, 3D, manufacturing, simulation, adaptive	Kolarevic, B. (113x) Menges, A. (86x) Gramazio, F. (69x) Oxman, R. (59x) Hensel, M. (52x) Oxman, N. (50x) Burry, M. (40x) Rippmann, M. (36x)	Gramazio, F., & Kohler, M. (2008). Digital materiality in architecture | Kolarevic, B., & Malkawi, A. (2005). Performative architecture: Beyond instrumentality | Kolarevic, B. (2003). Architecture in the Digital Age: Design and Manufacturing | Kolarevic, B., & Klinger, K. (2008). Manufacturing Material Effects: Rethinking Design and Making in Architecture | Khoshnevis, B. (2004). Automated construction by contour crafting—related robotics and information technologies
PARAMETRIC DESIGN 211 articles	parametric design, architectural design, parametric modeling, design process, parametric, systems, performance, tools, designers, planning, urban	Woodbury, R. (53x) Simon, H. (28x) Davis, D. (21x) Eastman, C. (19x) Akin, O. (17x) Aish, R. (16x) Davis, M. (14x) Oxman, R. (13x)	Woodbury, R. (2010). Elements of parametric design | Woodbury, R., & Burrow, A. (2006). Whither Design Space? | Davis, D. (2013). Modelled on Software Engineering: Flexible Parametric Models in the Practice of Architecture | Newell, A., & Simon, H. A. (1972). Human problem solving | Aish, R., & Woodbury, R. (2005). Multi-level Interaction in Parametric Design
ARCHIPELAGO OF EARLY EXPERIMENTS 623 articles	design process, virtual reality, architectural design, planning, urban, construction, decision, systems, simulation, CAD, environment, computer, evaluation, algorithm, new, optimization, automated	Mitchell, W. (30x) Keeney, R. (28x) Foley, J. (26x) Saaty, T. (26x) Simon, H. (26x) Miller, G. (25x) Church, R. (24x) Sutherland, I. (20x)	Keeney, R. L., & Raiffa, H. (1976). Decisions with multiple objectives: Preferences and value trade-offs | Miller, G. A. (1994). The magical number seven, plus or minus two: Some limits on our capacity for processing information | Cohon, J. L. (1978). Multiobjective programming and planning | Lynch, K. (1960). The Image of the City | Kirkpatrick, S., Gelatt, C., & Vecchi, M. (1983). Optimization by Simulated Annealing
THE SMITH GLITCH 176 articles	BIM adoption, construction, developed, planning, project, framework, time, systems, simulation	Smith, R. (25x) Smith, S. (24x) Smith, B. (16x) Smith, G. (16x) Smith, D. (15x) Shah, J. (12x) Smith, A. (12x) Smith, T. (12x)	Smith, B. (1983). IGES: A Key to CAD/CAM Systems Integration | Smith, S. (1999). Earthmoving Productivity Estimation Using Linear Regression Techniques | Smith, L., Bratini, L., Chambers, D.-A., Jensen, R. V., & Romero, L. (2010). Between idealism and reality: Meeting the challenges of participatory action research | Shah, J. J., Shen, Y., & Shirur, A. (1994). Determination of machining volumes from extensible sets of design features | Chang, T. (1990). Expert Process Planning for Manufacturing
PRODUCT CONFIGURATORS 332 articles	solid model, mesh generation, product configuration, design process, algorithm, knowledge, construction, systems, surface, 3D, engineering, feature, geometric	Lee, J. (51x) Lee, S. (47x) Blacker, T. (33x) Lee, K. (29x) Lee, C. (26x) Owen, S. (26x) Lee, Y. (23x) George, P. (22x)	Mittal, S., & Frayman, F. (1989). Towards a generic model of configuration tasks | Mittal, S., & Falkenhainer, B. (1990). Dynamic Constraint Satisfaction Problems | Blacker, T., & Stephenson, M. (1991). Paving: A new approach to automated quadrilateral mesh generation | Sabin, D., & Weigel, R. (1998). Product configuration frameworks — a survey | Price, M., Armstrong, C., & Sabin, M. (1995). Hexahedral mesh generation by medial surface subdivision: Part I. Solids with convex edges
BUILDING INFORMATION MODELING (BIM) 283 articles	BIM, IFC, AEC, semantic web technologies, construction industry, ontology-based, project, management, tools, knowledge, framework, automated, performance, checking, representation, energy, safety, collaborative	Eastman, C. (239x) Gruber, T. (62x) Sacks, R. (47x) Azhar, S. (43x) Lee, G. (39x) Zhang, S. (35x) Beetz, J. (34x) Pauwels, P. (33x)	Eastman, C. M., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers designers, engineers, and contractors. | Gruber, T. (1993). A translation approach to portable ontology specifications | Eastman, C., Lee, J.m., Jeong, Y.s., & Lee, J.k. (2009). Automatic rule-based checking of building designs | Eastman, C. (1999). Building Product Models: Computer Environments, Supporting Design and Construction
GEOMETRIC & SOLID MODELING 351 articles	geometric constraints, point cloud, boolean operations, data structure, CAD, 3D, solid, surface reconstruction, mesh, algorithm, representation, tolerance, boundary, parametric, topological, decomposition	Requicha, A. (140x) Hoffmann, C. (104x) Rossignac, J. (77x) Hoppe, H. (61x) Mäntylä, M. (53x) Amenta, N. (47x) Dey, T. (44x) Light, R. (44x)	Requicha, A. (1980). Representations for Rigid Solids: Theory, Methods, and Systems | Mäntylä, M. (1988). An introduction to solid modeling | Hoffmann, C. M. (1989). Geometric and solid modeling: An introduction | Light, R., & Gossard, D. (1982). Modification of geometric models through variational geometry | Bouma, W., Fudos, I., Hoffmann, C., Cai, J., & Paige, R. (1995). Geometric constraint solver
COMPUTER-AIDED MANUFACTURING (CAM) 1851 articles	BIM, tool path generation, SVM, genetic algorithm, particle swarm optimization, FEA, construction, real-time, AR, algorithm, surface, performance, simulation, 3D, management, machining, optimization, automated, CAD	Choi, B. (131x) Lee, S. (125x) Chen, Y. (118x) Wang, W. (115x) Lee, J. (111x) Liu, Y. (108x) Wang, J. (107x) Wang, X. (103x)	Choi, B., & Jerard, R. (1998). Sculptured Surface Machining: Theory and Applications | H. Persson (1978). NC machining of arbitrarily shaped pockets | Lonye, G., & Ozsoy, T. (1987). NC machining of free form surfaces | Suresh, K., & Yang, D. (1994). Constant Scallop-height Machining of Free-form Surfaces | Preparata, F., & Shamos, M. (1985). Computational Geometry: An Introduction
NURBS MODELING 549 articles	control points, B-spline, data points, Bézier curves, NURBS surfaces, subdivision surfaces, algorithm, geometric, shape, rational, interpolation, cubic, fitting, parametric, curvature, offset, patches, blending, freeform, planar	Piegl, L. (236x) Farin, G. (229x) Sederberg, T. (151x) Hoschek, J. (123x) Farouki, R. (111x) de Boor, C. (96x) Faux, I. (77x) Boehm, W. (75x)	Piegl, L. A., & Tiller, W. (1997). The NURBS book | Hoschek, J., & Lasser, D. (1996). Fundamentals of computer aided geometric design | de Boor, C. (1978). A practical guide to splines | Faux, I. D., & Pratt, M. J. (1979). Computational geometry for design and manufacture | Catmull, E., & Clark, J. (1978). Recursively generated B-spline surfaces on arbitrary topological meshes
CONSTRUCTION SITE SCANNING & TRACKING 191 articles	point cloud data, RFID, BIM, precast concrete elements, construction site, construction industry, real-time, safety, equipment, tracking, workers, management, 3D, automated, laser, monitoring, assessment, detection, performance, vision	Teizer, J. (85x) Tang, P. (69x) Bosche, F. (63x) Brilakis, I. (56x) Golparvar-fard, M. (53x) Song, J. (53x) Cheng, T. (52x) Navon, R. (48x)	Tang, P., Huber, D., Akinci, B., Lipman, R., & Lytle, A. (2010). Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques | Bosché, F. (2010). Automated recognition of 3D CAD model objects in laser scans and calculation of as-built dimensions for dimensional compliance control in construction | Teizer, J., Allread, B., Fullerton, C., & Hinze, J. (2010). Autonomous Pro-Active Real-time Construction Worker and Equipment Operator Proximity Safety Alert System | Song, J., Haas, C., Caldas, C., Ergen, E., & Akinci, B. (2006). Automating the task of tracking the delivery and receipt of fabricated pipe spools in industrial projects | Bosche, F., & Haas, C. (2008). Automated retrieval of 3D CAD model objects in construction range images