BIG DATA IN CIVIL ENGINEERING: A STATE-OF-THE-ART SURVEY

Oleg KAPLIŃSKIa, Natalija KOŠELEVAb, Guoda ROPAITĖc

aFaculty of Architecture, Poznan University of Technology, Nieszawska Str. 13, 60-965 Poznań, Poland
b, cVilnius Gediminas Technical University, Saulėtekio al. 11, LT-10233 Vilnius, Lithuania

Received 12 September 2016; accepted 16 September 2016

Abstract. Data generation has increased drastically over the past few years. Data management has also grown in importance because extracting the significant value out of a huge pile of raw data is of prime importance while making different decisions. This article reviews the concept of Big Data. The Thomson Reuters Web of Science Core Collection academic database was used to overview publications that contained “BIG DATA” keywords and were included in Web of Science Category under “Engineering”. The analysis of publications was made according to year, country, journal, authors, language and funding agency.

Keywords: engineering, Big Data, Web of Science.

Introduction

Generating of information from gained data is vitally important in terms of regulating life. Especially business enterprises need to store and transform data quickly and properly into information bases in order to achieve the objectives such as to be more competitive in the market, produce new products and be innovative. The increase in the amount of data sources also increases the amount of the data acquired. Therefore, storing and processing data has become difficult and classical approaches remain incapable to do it. Large amounts of data with a wide range can be stored, managed and processed using Big Data. Besides, Big Data ensures delivering proper information quickly and offers advantage and convenience to firms, researchers and consumers by taking the properties of Volume, Value, Variety, Veracity and Velocity into consideration (Ozkose et al. 2015).

1. Understanding of Big Data

Big Data is defined differently in literature. There is a number of definitions: Big Data is the amount of data beyond the ability of technology to store, manage and process efficiently. Big Data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization. Big Data Technologies are new generation technologies and architectures which were designed to extract value from multivariate high volume data sets efficiently by providing high speed capturing, discovering and analysing. As the definitions suggest, there are some points to be taken into consideration in Big Data sets. The data should be complex and multiple, and be of considerable size. Therefore conventional methods have difficulty in analysing Big Data sets and new methods and technologies are needed (Ozkose et al. 2015).

Big Data is a term for large and complex data sets, from music downloads to medical records and social media messages. Big Data is usually described by the four V’s:

1. Volume: scale of data;
2. Velocity: analysis of streaming data;
3. Variety: different forms of data;
4. Veracity: uncertainty of data (Moreno-Sandoval et al. 2015).
Big Data can be divided into 5 classes, regarding their characteristics: Data Sources (Web & Social, Machine, Sensing, Transactions and IoT), Content Format (Structured, Semi-Structured and Unstructured), Data Stores (Document-oriented, Column-oriented, Graph based and Key-value), Data Staging (Cleaning, Normalization and Transform) and Data Processing (Batch and Real time) (Ozkose et al. 2015).

Big data are worthless, if not managed and analysed for extracting useful information. Gandomi and Haider (2015) divide the overall process of extracting insights from big data into five stages, as shown in Figure 1. These five stages form the two main sub-processes: data management and analytics. Data management involves processes and supporting technologies to acquire and store data and to prepare and retrieve it for analysis. Analytics refers to techniques used to analyse and acquire intelligence from big data (Gandomi, Haider 2015).

There are several methods of the Big Data analysis, based on ways of data acquisition: text analytics, audio analytics, video analytics, social media analytics, and predictive analytics. Ozkose et al. (2015) define those methods as follows:

- **Text analytics** is used for information retrieval from data. E-mails, blogs, online forums, news and call center records are all examples of text data. Text analytics involve machine learning, statistical analysis and computational linguistics. Text analytics enable to extract meaningful summaries from large scale data. Information Extraction, Text Summarization, Question Answering and Sentiment Analysis are some of the techniques used in text analytics.

- **Audio Analytics** is used to extract information from unstructured audio data. Call centers and health services are commonly used utilization areas of audio analytics. Audio analytics can be used in numerous fields such as increasing the customer experience, the performance of customer representative and the sales rate; comprehending several tasks such as customer behaviors and the troubles of products.

- **Video analytics** is the usage of various techniques to extract meaningful information, track and analyze video streams. Marketing and operations management is the main application area of video analytics.

- **Social media analytics** is the analysis of the structured and unstructured data on the social media channels. Social media can be categorized as follows Social networks (Facebook, LinkedIn), Blogs (BlogSpot, WordPress), Microblogs (Twitter, Tumblr), Social news (Digg, Reddit), Social bookmarks (Delicious, StumbleUpon), Media sharing (Instagram, YouTube), Wiki (Wikipedia, Wikibook), Question-and-answer sites (Yahoo! Answers, Ask.com), Review sites (Yelp, TripAdvisor).

- **Predictive analytics** is based upon estimating future considering current or stale data. Predictive analysis is used to capture the relationships of data and discover the patterns. Predictive analytics which is primarily based on statistical methods is highly applicable on many disciplines.

Big Data is used efficiently in many fields of activity, such as: automotive industry; hi-tech; oil and gas industry; telecommunication sector, medicine and healthcare; media and show business; travel and transport sector; social media and online services; information and communication sector. One of the fields where Big Data can be sourced and transformed into the useful information is Civil Engineering.

### 2. Research methodology

In this paper, the literature related to Big Data has been reviewed comprehensively on the basis of papers referred in Thomson Reuters Web of Science academic database. Following the methodological analysis (Fig. 2) on the entire body of collected publications, a number of articles were reviewed from the first international publications in the area to date (January 2016). The presented research attempts to answer the following questions: (1) How have the papers been distributed by the period of publishing? (2) How have the papers been distributed by country? (3) How have the papers been distributed by author? (4) How have the papers been distributed by journal? (5) How have the papers been distributed by funding agency?
3. Number of publications by different databases and by year

The analysis of the subject of Big Data has been done online. 5160 publications were found, including articles (1619) in different databases (Fig. 3).

Mainly publication were found in Web of Science database. It contains 2664 referred publications (Fig. 4) on the topic of Big Data (15 January 2016), covering all types of documents, including articles (1060) (Table 1).

As depicted in Figure 3, the first scientific research on the topic of BIG DATA was done in 1974. The extent of research in the area has been rapidly increasing during the last ten years. Numbers of publications on BIG DATA increased from one-to-two papers per year up to 110 in 2012. More than 90 per cent of publications were published in the last three years (2013–2015).

As depicted in Figure 5, the first scientific research on the topic of Big Data in Civil Engineering was done in 2006. The extent of research in the area has been rapidly increasing during the last ten years, mostly in 2013 (195 articles per year).

Table 1. Publications on the topic of Big Data in Web of Science database

| Publications on Big Data | Number of Publications |
|-------------------------|------------------------|
| All                     | 2664                   |
| Articles                | 1060                   |
| Publications on Civil Engineering |                      |
| All                     | 590                    |
| Articles                | 139                    |
4. Number of publications: by country, author, journal, funding agency

Further, the analysis focused on the use of “BIG DATA + Civil Engineering” topic by country. The information is given in Figure 6. Articles were announced by researchers representing twenty six countries of the world. The leader is USA, where authors published 39 articles.

Authors listed in Table 2 published their articles on the topic of using Big Data in Civil Engineering.
The table demonstrates that Zhang XY and Chen JJ are leaders of this particular topic. They published 5 articles per each.

Table 3 provides information on journals in ISI Web of Science database, which issued articles on the Big Data use in Civil Engineering. In total, articles were published in 73 journals. The majority of articles – 15 – were published announced in IEEE Network. The second place, with 6 publications, is occupied by the International Journal of Production Economics and IEEE Transactions on Knowledge and Data Engineering.

Table 4 shows the number of publications on using Big Data in Civil Engineering in Web of Science Core Collection database by funding agencies. In total, articles were funded by 84 agencies. The leader is National Natural Science Foundation of China (20 articles). The second place, with 8 publications, is occupied by the National Science Foundation.

Table 2. Number of publications on the “BIG DATA + Civil Engineering” topic in Web of Science Core Collection database by author

| Author's name | Number of articles |
|---------------|-------------------|
| Zhang XY, Chen JJ | 5 |
| Giannakis GB, Liu C. | 4 |
| Slavakis K, Mateos G, Xu M, Cai H, Yang C, Dou WC. | 3 |
| Scutari G, Facchinei F, Wang W, Mu JS, Jeong YS, Herrera F, Del Rio S, Chen G, Anonymous, Wu XD, Wu GQ. | 2 |
| Xu J, Xu C, Xin JC, Wolff I, Wang S, Wang FY, Walter T, Vinsel L, Van Der Schaar M, Tsuda T, Tsuchiya S, Tsuchimoto Y, Triguero I, Traganitis PA, Tractenberg RE, Thilmany J, Tao F, Tanaka T, Tan KH, Taisch M, Sun JS, Sun J, Steinmann M, Stanek D, Song BY, Shi H, Shahabi C, Schmidt M, Schlieski T, Sato N, Sandryhaila A, Samuelson N, Sakamoto Y, Sait SY, Sagratella S, Liu Y, Liu JK, Liu JC, Liang S, Li ZX, Li Y, Li RM, Li JR, Li H, Lee V, Lee S, Lanman C, Kundra MK, Kumar PER, Kim SJ, Kim M, Kim HJ, Kim AS, Kido A, Ki SJ, Khare S, Kayahara A, Kang WW, Jones-Farmer LA, Johnson BD, Ji GJ, James C, Jackson K, Inoue S, Imai S, Huang GQ, Horta EG, Hong YL, Hong MY, Xian HJ, Sohn MD, Shin SS, Shibata T, Lan SL, Kurachi T, Kungurtsev V, Hazen BT, Han TT, Guo S. | 1 |

Table 3. Number of publications on the “BIG DATA + Civil Engineering” topic in Web of Science Core Collection database by journals total: (139)

| Source titles | Number of articles |
|---------------|-------------------|
| IEEE Network | 15 |
| International Journal of Production Economics | 6 |
| IEEE Transactions on Knowledge and Data Engineering | 6 |
| Mathematical Problems in Engineering | 5 |
| IEEE Signal Processing Magazine | 5 |
| Tsinghua Science and Technology | 5 |
| Transportation Research Part C Emerging Technologies | 5 |
| IEEE Transactions on Parallel and Distributed Systems | 5 |
| IEEE Intelligent Systems | 5 |
| IEEE Transactions on Signal Processing | 3 |
| Technology Review | 3 |
| Sea Technology | 3 |
| International Journal of Communication Systems | 3 |
| IEEE Transactions on Computers | 3 |
| IEEE Communications Magazine | 3 |
| Fuzzy Sets and Systems | 3 |
| Mechanical Engineering | 2 |
| IEEE Transactions on Semiconductor Manufacturing | 2 |
| IEEE Journal of Selected Topics in Signal Processing | 2 |
| Fujitsu Scientific Technical Journal | 2 |
| Other 53 journals* | 1 |

Notes: The following journals have one article each: Proceedings of the IEEE, Manufacturing Engineering, Korean Journal of Chemical Engineering, Journal of Modern Power Systems and Clean Energy, Journal of Industrial Ecology, Journal of Engineering Education, Int Journal Institute of Transportation Engineers, International Journal of Production Research, International Journal of Advanced Manufacturing Technology, IEEE Transactions on Intelligent Transportation Systems, IEEE Transactions on Image Processing, IEEE Spectrum, EURASIP Journal on Advances in Signal Processing, Eras Journal, Journal of Supercomputing, Journal of Sensors, International Journal of Software Engineering and Knowledge Engineering, Information an International Interdisciplinary Journal, IEEE Transactions on Information Forensics and Security, IEEE Transactions on Biomedical Engineering, IEEE Transactions on Bio Medical Engineering, Solid State Technology, Science and Engineering Ethics, Sadhana Academy Proceedings in Engineering Sciences, Quality Engineering, Ergonomics, Environmental Science Technology, Environmental Modelling Software, Desalination, Bell Labs Technical Journal,
Applied Energy, Advances in Mechanical Engineering, Transportation Research Record, Transportation Research Part D, Transport and Environment, IEEE Journal on Selected Areas in Communications, Engineering Technology Applied Science Research, Energy Policy, Computers Electrical Engineering, Cloud Services Networking and Management, Chemical Engineering News, Applied and Computational Harmonic Analysis, Ambio.

Table 4. Number of publications on the "BIG DATA + Civil Engineering" topic in Web of Science Core Collection database by funding agencies total: (139)

| Funding Agencies                                                      | Number of articles |
|-----------------------------------------------------------------------|--------------------|
| National Natural Science Foundation of China                          | 20                 |
| National Science Foundation                                           | 8                  |
| NSFC                                                                  | 6                  |
| Fundamental Research Funds for the Central Universities               | 5                  |
| National Science Foundation of China                                  | 4                  |
| Beijing Natural Science Foundation                                    | 4                  |
| National Basic Research Program of China                              | 3                  |
| Australian Research Council                                           | 3                  |
| US National Science Foundation                                        |                    |
| Tianjin Younger Natural Science Foundation                            | 2                  |
| SRF for Roc's Sem                                                     | 2                  |
| National Key Technology R D Program of the Ministry of Science and Technology | 2             |
| National Key Basic Research and Development 973 Program of China      | 2                  |
| National 973 Program of China                                         | 2                  |
| Muri                                                                   | 2                  |
| Miur Project Platino                                                   | 2                  |
| European Commission                                                   | 2                  |
| Basic Science Research Program Through The National Research Foundation of Korea NRF Ministry of Education Science and Technology | 2             |
| Other 66 funding agencies                                              | 1                  |

Notes: *The following funding agencies have one article each: Zhejiang Provincial Government, Wolf Creek Foundation, USA NSF Grant CMS, USA NSF Grant Career Award, USA National Science Foundation, US National Science Foundation NSF, United States Department of Agriculture National Agricultural Library, UK EPSRC Digital Economy Programme, U S Doe, U S Department of Energy Doe, Tsinghua Toshiba Energy and Environment Research Center, Toward World Class Universities Project of NTHU, Torres Quevedo Program, Tianjin Natural Science Foundation, Talent Projects of the Educational Department of Liaoning Province, Taiwan Semiconductor Manufacturing Company, Swiss Science Foundation, Strategic Priority Research Program of the Chinese Academy of Sciences, Strategic International Collaborative Research Program Sicorp Japanese JST U S NSF Joint, Research Big Data and Disaster Research BDD, Special Fund for Meteorological Research in the Public Interest from Ministry of Science and Industry of China, Spanish Ministry of Education Under a Fulbright be Grant, Spanish Ministry of Education and Science, Social Sciences and Humanities Research Council of Canada SSHRC, Shenzhen Foundational Research Projects, Seaver Institute, RWTH Research Fellowship Funded Through the Excellence Initiative of the German Federal and State Governments, RWTH Aachen University Through the UMIC Research Center, RGC Hong Kong, RGC HK, RGC GRF Polyu, Ramco Cements Limited, Qinhuangdao Traffic Management Bureau, Provincial Natural Science Foundation, Program for Excellent Talents in Beijing, Program for Changjiang Scholars and Innovative Research Team in University PCSIRT of the Ministry of Education of China, Professor Nigel H M Wilson of Massachusetts Institute of Technology, Privacy Aware Retrieval and Modelling of Genomic DATA, Postdoctoral Science Foundation of China, PHR, NSFC Innovation Research Group, NSF US, NSF Grants, NSF China, NSF, NSERC Strategic Project Grant, NSERC Discovery Grant, NSERC Canada, NPRP from the Qatar National Research Fund a Member of the Qatar Foundation, Nottingham University Business School Spark Fund, NIH Nida, NCETFJ, NCET, Natural Sciences and Engineering Research Council of Canada NSERC, Natural Science Foundation of USA, Natural Science Foundation of Fujian Province of China, Natural Science Foundation of Fujian, National University of Singapore Research Grant, National Training Program of Innovation and Entrepreneurship for Undergraduates, National Science Foundation of the US, National Science Foundation for Distinguished Young Scholars of China, National Science Council of Taiwan ROC, National Research Foundation of Korea NRF Korea Government MSIP, National Natural Science Foundation of China A5 Program, National Natural Science Foundation, National High Tech Research and Development 863 Program of China, National Center for Research Resources, FP7 Calipso European Project, Fapemig, European Union, European Social Fund, ERM Group Foundation, ERC, Dupont Young Professor Grant, DOW Sustainability Fellowship Program, DOD, Department of Science and Technology DST Government of India, Department of Industry Australia, Department of Energy, CSIRO Office of Chief Executive Top up PHD Scholarship, Comba Fund, Collaborative Innovation Center for Capital World City S Smooth Traffic Construction, Cityu Teaching Development Grant.

Conclusions

The first scientific research on Big Data was done in 1974, but the main research started only in early 2000.

The breakthrough in Big Data occurred only in 2012.

Currently, Thomson Reuters Web of Science Core Collection quotes 2664 publications on a topic of Big Data, 1060 of which are articles.

The interest in the topic of Big Data in Civil Engineering rapidly increases, 590 articles in Thomson Reuters Web of Science Core Collection were categorized as part of this topic beginning from 2006.

Most publications (39) were announced by researchers in the USA. The second place is occupied by Chinese researchers with 22 publications.

The majority of publications (15) were printed in the IEEE Network journal. The second place, with 6 articles, is occupied by the International Journal of Production Economics and IEEE Transactions on Knowledge and Data Engineering.
References

Aydin, G.; Hallac, I. R.; Karakus, B. 2015. Architecture and implementation of a scalable sensor data storage and analysis system using cloud computing and Big Data technologies, Journal of Sensors, Article No. 834217. https://doi.org/10.1155/2015/834217

Barnaghi, P.; Sheth, A.; Henson, C. 2013. From data to actionable knowledge: Big Data challenges in the web of things, IEEE Intelligent Systems 28(6): 6–11. https://doi.org/10.1109/MIS.2013.142

Betser, J; Hecht, M. 2015. Big Data on clouds (BDOC), in N. L. S. da Fonseca, R. Boutaba (Eds.). Cloud Services, Networking, and Management. John Wiley & Sons, Inc., 361–391.

Chen, Z.; Wen, Y.; Cao, J. 2015. A survey of bitmap index compression algorithms for Big Data, Tsinghua Science and Technology 20(1): 100–115. https://doi.org/10.1016/j.trt.2014.09.003

Cai, H.; Xu, M. 2013. Greenhouse gas implications of fleet electrification based on Big Data-informed individual travel patterns, Environmental Science & Technology 47(16): 9035–9043. https://doi.org/10.1021/es401008f

Cevher, V.; Becker, S.; Schmidt, M. 2014. Convex optimization for Big Data, IEEE Signal Processing Magazine 31(5): 32–43. https://doi.org/10.1109/MSP.2014.2329397

Chen, Z.; Wen, Y.; Cao, J. 2015. A survey of bitmap index compression algorithms for Big Data, Tsinghua Science and Technology 20(1): 100–115. https://doi.org/10.1016/j.trt.2014.09.003

Chen, C. F.; Chuang, S. C. 2014. A framework for root cause detection of sub-batch processing system for semiconductor manufacturing Big Data analytics, IEEE Transactions on Semiconductor Manufacturing 27(4): 475–488. https://doi.org/10.1109/TSM.2014.2356555

Chui, C. K.; Filibir, F.; Mhaskar, H. N. 2015. Representation of functions on Big Data: Graphs and trees, Applied and Computational Harmonic Analysis 38(3): 489–509. https://doi.org/10.1016/j.acha.2014.06.006

Cooper, J.; Noon, M.; Jones, C. 2013. Big Data in life cycle assessment, Journal of Industrial Ecology 17(6): 796–799. https://doi.org/10.1111/jiec.12069

Dai, X.; Zhu, P.; Yang, X. 2014. Optimized Big Data K-means clustering using Map Reduce, Journal of Supercomputing 70(3): 1249–1259. https://doi.org/10.1007/s11227-014-1225-7

Daneshmand, A.; Facchinei, F.; Kungurtsev, V. 2015. Hybrid random/deterministic parallel algorithms for convex and nonconvex Big Data optimization, IEEE Transactions on Signal Processing 63(15): 3914–3929. https://doi.org/10.1109/TSP.2015.2436357

Dey, B.; Kundu, M. K. 2015. Efficient foreground extraction from HEVC compressed video for application to real-time analysis of surveillance “big” data, IEEE Transactions on Image Processing 24(11): 3574–3585. https://doi.org/10.1109/TIP.2015.2445631

Ding, L.; Liu, Y.; Song, B. 2015. Efficient ELM-based two stages query processing optimization for Big Data, Mathematical Problems in Engineering, Article No. 236084. https://doi.org/10.1155/2015/236084

Dong, H.; Wu, M.; Ding, X. 2015. Traffic zone division based on Big Data from mobile phone base stations, Transportation Research Part C: Emerging Technologies 58: 278–291. https://doi.org/10.1016/j.trc.2015.06.007

Dong, X.; Li, R.; He, H. 2015. Secure sensitive data sharing on a Big Data platform, Tsinghua Science and Technology 20(1): 72–80. https://doi.org/10.1109/TST.2015.7040516

Dou, W.; Zhang, X.; Liu, J. 2015. HireSome-II: towards privacy-aware cross-cloud service composition for Big Data applications, IEEE Transactions on Parallel and Distributed Systems 26(2): 455–466. https://doi.org/10.1109/TPDS.2013.246

Driscoll, R.; Balog, B. 2015. Multicasting technology to meet increased broadband demands at sea IP-Mobilecast delivers Big Data to multiple vessels simultaneously, Sea Technology 56(5): 19–22.

Drury, C. G. 2015. Human factors/ergonomics implications of Big Data analytics: Chartered Institute of Ergonomics and Human Factors annual lecture, Ergonomics 58(5): 659–673. https://doi.org/10.1080/00140139.2015.1025106

Dutta, D.; Bose, I. 2015. Managing a Big Data project: the case of Ramco Cements Limited, International Journal of Production Economics 165: 293–306. https://doi.org/10.1016/j.ijpec.2014.12.032

Erdman, A. G.; Keefe, D. F.; Schieselt, R. 2013. Grand challenge: applying regulatory science and Big Data to improve medical device innovation, IEEE Transactions on Biomedical Engineering 60(3): 700–706. https://doi.org/10.1109/TBME.2013.2244600

Erturk, E.; Jyoti, K. 2015. Perspectives on a Big Data application: what database engineers and it students need to know, Engineering Technology & Applied Science Research 5(5): 850–853.

Facchinei, F.; Scutari, G.; Sagratella, S. 2015. Parallel selective algorithms for nonconvex Big Data optimization, IEEE Transactions on Signal Processing 63(7): 1874–1889. https://doi.org/10.1109/TSP.2015.2399858

Fang, H.; Zhang, Z.; Wang, C. J. 2015. A survey of Big Data research, IEEE Network 29(5): 6–9. https://doi.org/10.1109/MNET.2015.7293298

Fernandez, A.; Gomez, A.; Lecumberry, F. 2015. Pattern recognition in Latin America in the “Big Data” era, Pattern Recognition 48(4): 1185–1196. https://doi.org/10.1016/j.patcog.2014.04.012

Fu, J.; Chen, Z.; Wang, J. 2012. Distributed storage system Big Data mining based on HPC application-a solar photovoltaic forecasting system practice, Information – An International Interdisciplinary Journal 15(9): 3749–3755.

Gandomi, A.; Haider, M. 2015. Beyond the hype: Big Data concepts, methods, and analytics, International Journal of Information Management 35: 137–144. https://doi.org/10.1016/j.jijinfmt.2014.10.007

Gkiotsalitis, K.; Stathopoulos, A. 2015. A utility-maximization model for retrieving users' willingness to travel for participating in activities from Big-data, Transportation Research Part C: Emerging Technologies 58(2): 265–277. http://dx.doi.org/10.1016/j.trc.2014.12.006
Mai, H. T.; Park, K. H.; Lee, H. S. 2014. Dynamic data migration in hybrid main memories for in-memory Big Data storage, *ETRI Journal* 36(6): 988–998. https://doi.org/10.4218/etrij.14.0114.0012

Mao, R.; Xu, H.; Wu, W. 2015. Overcoming the challenge of variety: Big Data abstraction, the next evolution of data management for AAL communication systems, *IEEE Communications Magazine* 53(1): 42–47. https://doi.org/10.1109/MCOM.2015.7010514

Mardani, M.; Mateos, G.; Giannakis, G. B. 2015. Subspace learning and imputation for streaming Big Data matrices and tensors, *IEEE Transactions on Signal Processing* 63(10): 2663–2677. https://doi.org/10.1109/TSP.2015.2417491

Mashayekhy, L.; Nejad, M. M.; Grosu, D. 2015. Energy-aware scheduling of MapReduce jobs for Big Data applications, *IEEE Transactions on Parallel and Distributed Systems* 26(10): 2720–2733. https://doi.org/10.1109/TPDS.2014.2358556

Mathew, P. A.; Dunn, L. N.; Sohn, M. D. 2015. Big-data for building energy performance: lessons from assembling a very large national database of building energy use, *Applied Energy* 140: 85–93. https://doi.org/10.1016/j.apenergy.2014.11.042

Meeker, W. Q.; Hong, Y. 2014. Reliability meets Big Data: opportunities and challenges, *Quality Engineering* 26(1): 102–116. https://doi.org/10.1080/08982112.2014.846119

Meng, S.; Dou, W.; Zhang, X. 2014. KASR: a keyword-aware service recommendation method on MapReduce for Big Data applications, *IEEE Transactions on Parallel and Distributed Systems* 25(12): 3221–3231. https://doi.org/10.1109/TPDS.2013.2297117

Milan, R. T.; Stanek, D.; Jackson, K. 2014. The first penguin through the Big Data ice hole: using cell phone and GPS data to improve integrated models, *ITE Journal-Institute of Transportation Engineers* 25(12): 3221–3231.

Moreno-Sandoval, A.; Moro, E. 2015. Big Data versus small data: the case of "gripe" (flu) in Spanish, *Procedia – Social and Behavioral Sciences* 198: 339–343. https://doi.org/10.1016/j.sbspro.2015.07.452

Muirhead, G. 2015. Meeting the Big Data challenge the European data relay system, *ESA Bulletin – European Space Agency* 162: 10–17.

Mullin, R. 2014. Taking Big Data to the bench, *Chemical & Engineering News* 92(23): 19–21. https://doi.org/10.1021 cen-09223-bus1

Nativi, S.; Mazzetti, P.; Santoro, M. 2015. Big Data challenges in building the Global Earth Observation System of Systems, *Environmental Modelling & Software* 68: 1–26. https://doi.org/10.1016/j.envsoft.2015.01.017

Noll, G.; Hogeweg, M. 2015. Big Data management at Port of Rotterdam using a GIS platform to streamline IT at growing maritime hub, *Sea Technology* 56(5): 31.

Noor, A. K. 2013. Putting Big Data to work, *Mechanical Engineering* 135(10): 32–37.

O’Leary, Daniel E. 2013. Artificial intelligence and Big Data, *IEEE Intelligent Systems* 28(2): 96–99. https://doi.org/10.1109/MIS.2013.39

Opresnik, D.; Taisch, M. 2015. The value of Big Data in servitization, *International Journal of Production Economics* 165: 174–184. https://doi.org/10.1016/j.ijpe.2014.12.036

Otero, C. E.; Peter, A. 2015. Research directions for engineering Big Data analytics software, *IEEE Intelligent Systems* 30(1): 13–19. https://doi.org/10.1109/MIS.2014.76

Ozkose, H.; Ari, E.; Gencer, C. 2015. Yesterday, today and tomorrow of Big Data, *Procedia – Social and Behavioral Sciences* 195: 1042–1050. https://doi.org/10.1016/j.sbspro.2015.06.147

Park, J.; Kim, H.; Jeong, Y. S. 2014. Two-phase grouping-based resource management for Big Data processing in mobile cloud computing, *International Journal of Communication Systems* 27(6): 839–851. https://doi.org/10.1002/dac.2627

Peng, Z.; Peng, J.; Zhao, W. 2015. Research on FCM and NHL based high order mining driven by Big Data, *Mathematical Problems in Engineering*, Article No. 802505. https://doi.org/10.1155/2015/802505

Pentland, A. 2014. Saving Big Data from itself, *Scientific American* 311(2): 64–67. https://doi.org/10.1038/scientificamerican0814-64

Peralta, D.; Del Rio, S.; Ramirez-Gallego, S. 2015. Evolutionary feature selection for Big Data classification: a MapReduce approach, *Mathematical Problems in Engineering*, Article No. 246139. https://doi.org/10.1155/2015/246139

Perrons, R. K.; Jensen, J. W. 2015. Data as an asset: what the oil and gas sector can learn from other industries about “Big Data”, *Energy Policy* 81: 117–121. https://doi.org/10.1016/j.enpol.2015.02.020

Pijanowski, B. C.; Tayyebi, A.; Doucette, J. 2014. A Big Data urban growth simulation at a national scale: configuring the GIS and neural network based Land Transformation Model to run in a High Performance Computing (HPC) environment, *Environmental Modelling & Software* 51: 250–268. https://doi.org/10.1016/j.envsoft.2013.09.015

Priya, M.; Kumar, P. R. 2015. A novel intelligent approach for predicting atherosclerotic individuals from Big Data for healthcare, *International Journal of Production Research* 53(24): 7517–7532. https://doi.org/10.1080/00207543.2015.1087655

Purcell, R. H.; Rommelfanger, K. S. 2015. Internet-based brain training games, citizen scientists, and Big Data: ethical issues in unprecedented virtual territories, *Neuron* 86(2): 356–359. https://doi.org/10.1016/j.neuron.2015.03.044

Qu, Z.; Chen, G. 2015. Big Data compression processing and verification based on Hive for smart substation, *Journal of Modern Power Systems and Clean Energy* 3(3): 440–446. https://doi.org/10.1007/s40565-015-0144-9

Reitenbach, G. 2016. Big Data and the industrial internet meet the power plant, *Power* 160(1): 26–31.

Sait, S. Y.; Bhandari, A.; Khare, S. 2015. Multi-level anomaly detection: relevance of Big Data analytics in networks, *Sadhana – Academy Proceedings in Engineering Sciences* 40(6): 1737–1767. https://doi.org/10.1007/s13326-015-0416-0

Samuelson, N.; Poczek, C.; Lanman, C. 2014. Harnessing Big Data, *Solid State Technology* 57(5): 43–44.

Sandryhaila, A.; Moura, J. M. F. 2014. Big Data analysis with signals on graphs, *IEEE Signal Processing Magazine* 31(5): 80–90. https://doi.org/10.1109/MSP.2014.2329213

Sanjeev, I. 2015. Scalable algorithms for large and dynamic networks: reducing Big Data for small computations, *Bell Labs Technical Journal* 20: 23–33. https://doi.org/10.15325/BLTJ.2015.2437465
Schlieski, T.; Johnson, B. D. 2012. Entertainment in the age of Big Data, Proceedings of the IEEE 100: 1404–1408. https://doi.org/10.1109/JPROC.2012.2189918

Shi, H.; Kim, M. J.; Lee, S. C. 2015. Localized indoor air quality monitoring for indoor pollutants’ healthy risk assessment using sub-principal component analysis driven model and engineering Big Data, Korean Journal of Chemical Engineering 32(10): 1960–1969. https://doi.org/10.1007/s11814-015-0042-x

Shibata, T.; Kurachi, T. 2015. Big Data analysis solutions for driving innovation in on-site decision making, Fujitsu Scientific & Technical Journal 51(2): 33–41.

Slavakis, K.; Giannakis, G. B.; Mateos, G. 2014. Modeling and optimization for Big Data analytics, IEEE Signal Processing Magazine 31(5): 18–31. https://doi.org/10.1109/MSP.2014.2327238

Slavakis, K.; Kim, S. I.; Mateos, G. 2014. Stochastic approximation vis-a-vis online learning for Big Data analytics, IEEE Signal Processing Magazine 31(6): 124–129. https://doi.org/10.1109/MSP.2014.2345536

Sptijs, J.; T’Joens, Y.; Dragnea, R. 2014. Using Big Data to improve customer experience and business performance, Bell Labs Technical Journal 18(4): 3–17. https://doi.org/10.1002/bltj.21642

Stickler, G. 2015. Ship view simplifies tracking of global shipping user-friendly software service maps Big Data quickly via web, Sea Technology 56(3): 10–12.

Sun, J.; Xu, W.; Ma, J. 2015. Leverage RAF to find domain experts on research social network services: a Big Data analytics methodology with MapReduce framework, International Journal of Production Economics 165: 185–193. https://doi.org/10.1016/j.ijpe.2014.12.038

Talbot, D. 2013. Big Data from cheap phones, Technology Review 116(3): 50–54.

Tan, K. H.; Zhan, Y. Z.; Ji, G. 2015. Harvesting Big Data to enhance supply chain innovation capabilities: an analytic infrastructure based on deduction graph, International Journal of Production Economics 165: 223–233. https://doi.org/10.1016/j.ijpe.2014.12.034

Tannahill, B. K.; Jamshidi, M. 2014. System of Systems and Big Data analytics – Bridging the gap, Computers & Electrical Engineering 40(1): 2–15. https://doi.org/10.1016/j.compeleceng.2013.11.016

Thilmany, J. 2014. Beyond Scada: Really Big Data, Mechanical Engineering 136(3): 36–41.

Toole, J. L.; Colak, S.; Sturt, B. 2015. The path most traveled: travel demand estimation using Big Data resources, Transportation Research Part C-Emerging Technologies 58: 162–177. https://doi.org/10.1016/j.trc.2015.04.022

Trachtenberg, R. E.; Russell, A. J.; Morgan, G. J. 2015. Using ethical reasoning to amplify the reach and resonance of professional codes of conduct in training Big Data scientists, Science and Engineering Ethics 21(6): 1485–1507. https://doi.org/10.1007/s11948-014-9613-1

Traganitis, P. A.; Slavakis, K.; Giannakis, G. B. 2015. Sketch and Validate for Big Data clustering, IEEE Journal of Selected Topics in Signal Processing 9(4): 678–690. https://doi.org/10.1109/JSTSP.2015.2396477

Tsuchiya, S.; Sakamoto, Y.; Tsuchimoto, Y. 2012. Big Data processing in cloud environments, Fujitsu Scientific & Technical Journal 48(2): 159–168.

Tsuda, T.; Inoue, S.; Kayahara, A. 2015. Advanced semiconductor manufacturing using Big Data, IEEE Transactions on Semiconductor Manufacturing 28(3): 229–235. https://doi.org/10.1109/TSM.2015.2445320

Vij, A.; Shankari, K. 2015. When is Big Data Big enough? Implications of using GPS-based surveys for travel demand analysis, Transportation Research Part C-Emerging Technologies 56: 446–462. https://doi.org/10.1016/j.trc.2015.04.025

Vilajosana, I.; Llosa, J.; Martinez, B. 2013. Bootstrapping smart cities through a self-sustainable model based on Big Data flows, IEEE Communications Magazine 51(6): 128–134. https://doi.org/10.1109/MCOM.2013.6525605

Wang, D.; Liu, J. 2015. Optimizing Big Data processing performance in the public cloud: opportunities and approaches, IEEE Network 29(5): 31–35. https://doi.org/10.1109/MNET.2015.7293302

Wang, R.; He, Y. L.; Chow, C. Y. 2015. Learning ELM-Tree from Big Data based on uncertainty reduction, Fuzzy Sets and Systems 258: 79–100. https://doi.org/10.1016/j.fss.2014.04.028

Wang, S.; Wang, X.; Huang, J. 2015. Analyzing the potential of mobile opportunistic networks for Big Data applications, IEEE Network 29(5): 57–63. https://doi.org/10.1109/MNET.2015.7293306

Wang, W.; Chen, Z.; Mu, J. 2014. Throat polygpy detection based on compressed Big Data of voice with support vector machine algorithm, Eurasip Journal on Advances in Signal Processing, Article No. 1.

Wang, W.; Lu, D.; Zhou, X. 2013. Statistical wavelet-based anomaly detection in Big Data with compressive sensing, Eurasip Journal on Wireless Communications and Networking, Article No. 269. https://doi.org/10.1186/1687-1499-2013-269

Wolff, I. 2015. New software puts Big Data to practical specific use, Manufacturing Engineering 155(2): 49.

Wu, C. J.; Ku, C. F.; Ho, J. M. 2016. A novel pipeline approach for efficient Big Data broadcasting, IEEE Transactions on Knowledge and Data Engineering 28(1): 17–28. https://doi.org/10.1109/TKDE.2015.2468714

Wu, X.; Chen, H.; Wu, G. Q. 2015. Knowledge engineering with Big Data, IEEE Intelligent Systems 30(5): 46–55. https://doi.org/10.1109/MIS.2015.56

Wu, X.; Zhu, X.; Wu, G. Q. 2014. Data mining with Big Data, IEEE Transactions on Knowledge and Data Engineering 26(1): 97–107. https://doi.org/10.1109/TKDE.2013.109

Xian, H.; Madhavan, K. 2014. Anatomy of scholarly collaboration in engineering education: a Big-Data bibliometric analysis, Journal of Engineering Education 103(3): 486–514. https://doi.org/10.1002/j ee.20052

Xu, J.; Deng, D.; Demiryurek, U. 2015. Mining the situation: spatiotemporal traffic prediction with Big Data, IEEE Journal of Selected Topics in Signal Processing 9(4): 702–715. https://doi.org/10.1109/JSTSP.2015.2389196

Xu, M.; Cai, H.; Liang, S. 2015. Big Data and industrial ecology, Journal of Industrial Ecology 19(2): 205–210. https://doi.org/10.1111/jiec.12241
Xu, T.; Wang, D.; Liu, G. 2015. Banian: a cross-platform interactive query system for structured Big Data, *Tsinghua Science and Technology* 20(1): 62–71. https://doi.org/10.1109/TST.2015.7040514

Xu, W. J.; Zhao, C. D.; Chiang, H. P. 2015. The RR-PEVQ algorithm research based on active area detection for Big Data applications, *Multimedia Tools and Applications* 74(10): 3507–3520. https://doi.org/10.1007/s11042-014-1903-8

Yang, K.; Jia, X.; Ren, K. 2015. Secure and verifiable policy update outsourcing for Big Data access control in the cloud, *IEEE Transactions on Parallel and Distributed Systems* 26(12): 3461–3470. https://doi.org/10.1109/TPDS.2014.2380373

Yi, X.; Liu, F.; Liu, J. 2014. Building a network highway for Big Data: architecture and challenges, *IEEE Network* 28(4): 5–13. https://doi.org/10.1109/MNET.2014.6863125

Yin, H.; Jiang, Y.; Lin, C. 2014. Big Data: transforming the design philosophy of future internet, *IEEE Network* 28(4): 14–19. https://doi.org/10.1109/MNET.2014.6863126

Zhang, D. 2013. Granularities and inconsistencies in Big Data analysis, *International Journal of Software Engineering and Knowledge Engineering* 23(6): 887–893. https://doi.org/10.1142/S0218194013500241

Zhang, H.; Chen, G.; Ooi, B. C. 2015. In-Memory Big Data management and processing: a survey, *IEEE Transactions on Knowledge and Data Engineering* 27(7): 1920–1948. https://doi.org/10.1109/TKDE.2015.2427795

Zhang, H.; Zhang, Q.; Zhou, Z. 2015. Processing geo-dispersed Big Data in an advanced MapReduce framework, *IEEE Network* 29(5): 24–30. https://doi.org/10.1109/MNET.2015.7293301

Oleg KAPLIŃSKI is Professor of Civil Engineering at Faculty of Architecture (IAP), Poznan University of Technology, Poznan, Poland. He lectures economics and organization of the investment process, as well as the theory and principles of work place design. The author of 250 publications. Doctor Honoris Causa of VGTU (1996). Member of the CE Committee of the Polish Academy of Sciences. His current research are: an integral management, integral design, risk management, theory of decision making and research methods in CE and architecture.

Natalija KOŠELEV A is a second year PhD student at the Faculty of Civil Engineering, Department of Construction Technology and Management at Vilnius Gediminas Technical University.

Guoda ROPAITĖ is a second year PhD student at the Faculty of Civil Engineering, Department of Construction Technology and Management at Vilnius Gediminas Technical University.

Natalija KOŠELEV A is a second year PhD student at the Faculty of Civil Engineering, Department of Construction Technology and Management at Vilnius Gediminas Technical University.