Authors	Year	Source title	Cited by	DOI	Title	Abstract	Purpose	Findings	Author Keywords	Index Keywords	CATEGORY-1	CATEGORY-2
Motamedi A.	2014	Automation in Construction	117	10.1016/j.autcon.2014.03.012	Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management	Facilities managers need to identify failure cause-effect patterns in order to prepare corrective and preventive maintenance plans. This task is difficult because of the complex interaction and interdependencies between different building components. Standardization based on Building Information Modeling (BIM) provides new opportunities to improve the efficiency of facilities management (FM) operations by sharing and exchanging building information between different applications throughout the lifecycle of the facilities. This paper aims to utilize BIM visualization capabilities to provide FM technicians with visualizations that allow them to utilize their cognitive and perceptual reasoning for problem solving. It investigates a knowledge-assisted BIM-based visual analytics approach for failure root-cause detection in FM. For this purpose, the inspection and maintenance data of Computerized Maintenance Management System (CMMS) are integrated with a BIM. Moreover, various sources of building knowledge such as fault trees and relationships between components are formally represented. These resources are used to create custom visualizations through an interactive user interface which helps in exploiting the heuristic problem solving ability of field experts to find root causes of failures in a building. © 2014 Elsevier B.V.	This paper aims to utilize BIM visualization capabilities to provide FM technicians with visualizations that allow them to utilize their cognitive and perceptual reasoning for problem solving. It investigates a knowledge-assisted BIM-based visual analytics approach for failure root-cause detection in FM.	These resources are used to create custom visualizations through an interactive user interface which helps in exploiting the heuristic problem solving ability of field experts to find root causes of failures in a building.	BIM, Facilities management, Fault tree analysis, Maintenance management, Visual analytics	Fault tree analysis, Forestry, Problem solving, Information management, Preventive maintenance, User interfaces, Visualization, BIM, Building Information Model - BIM, Computerized maintenance management system, Corrective and preventive maintenance, Facilities management, Interactive user interfaces, Maintenance management, Visual analytics, Architectural design, Forestry, Information Retrieval, Interfaces, Preventive Maintenance	Management	BIM
Han K.K.	2017	Automation in Construction	92	10.1016/j.autcon.2016.11.004	Potential of big visual data and building information modeling for construction performance analytics: An exploratory study	The ever increasing volume of visual data due to recent advances in smart devices and camera-equipped platforms provides an unprecedented opportunity to visually capture actual status of construction sites at a fraction of cost compared to other alternatives methods. Most efforts on documenting as-built status, however, stay at collecting visual data and updating BIM. Hundreds of images and videos are captured but most of them soon become useless without properly being localized with plan document and time. To take full advantage of visual data for construction performance analytics, three aspects (reliability, relevance, and speed) of capturing, analyzing, and reporting visual data are critical. This paper 1) investigates current strategies for leveraging emerging big visual data and BIM in construction performance monitoring from these three aspects, 2) characterizes gaps in knowledge via case studies and structures a road map for research in visual sensing and analytics. © 2016 Elsevier B.V.	This paper 1) investigates current strategies for leveraging emerging big visual data and BIM in construction performance monitoring from these three aspects, 2) characterizes gaps in knowledge via case studies and structures a road map for research in visual sensing and analytics.	To take full advantage of visual data for construction performance analytics, three aspects (reliability, relevance, and speed) of capturing, analyzing, and reporting visual data are critical.	Big visual data, Construction progress monitoring, Images, Point cloud, Quality control, Videos	Data visualization, Construction progress, Knowledge management, Quality control, Images, Point cloud, Videos, Visual data, Architectural design	Management	BIM
Bilal M.	2016	Journal of Building Engineering	68	10.1016/j.jobe.2016.03.002	Big data architecture for construction waste analytics (CWA): A conceptual framework	In recent times, construction industry is enduring pressure to take drastic steps to minimise waste. Waste intelligence advocates retrospective measures to manage waste after it is produced. Existing waste intelligence based waste management software are fundamentally limited and cannot facilitate stakeholders in controlling wasteful activities. Paradoxically, despite a great amount of effort, the waste being produced by the construction industry is escalating. This undesirable situation motivates a radical change from waste intelligence to waste analytics (in which waste is propose to be tackle proactively right at design through sophisticated big data technologies). This paper highlight that waste minimisation at design (a.k.a. designing-out waste) is data-driven and computationally intensive challenge. The aim of this paper is to propose a Big Data architecture for construction waste analytics. To this end, existing literature on big data technologies is reviewed to identify the critical components of the proposed Big Data based waste analytics architecture. At the crux, graph-based components are used: in particular, a graph database (Neo4J) is adopted to store highly voluminous and diverse datasets. To complement, Spark, a highly resilient graph processing system, is employed. Provision for extensions through Building Information Modelling (BIM) are also considered for synergy and greater adoption. This symbiotic integration of technologies enables a vibrant environment for design exploration and optimisation to tackle construction waste. The main contribution of this paper is that it presents, to the best of our knowledge, the first Big Data based architecture for construction waste analytics. The architecture is validated for exploratory analytics of 200,000 waste disposal records from 900 completed projects. It is revealed that existing waste management software classify the bulk of construction waste as mixed waste, which exposes poor waste data management. The findings of this paper will be of interest, more generally to researchers, who are seeking to develop big data based simulation tools in similar non-trivial applications. © 2016 Elsevier Ltd. All rights reserved.	The aim of this paper is to propose a Big Data architecture for construction waste analytics. To this end, existing literature on big data technologies is reviewed to identify the critical components of the proposed Big Data based waste analytics architecture.	The findings of this paper will be of interest, more generally to researchers, who are seeking to develop big data based simulation tools in similar non-trivial applications.	Big data analytics, Building information modelling (BIM), Construction waste, Construction waste analytics, Design optimisation, Waste prediction and minimisation	Architectural design, Design, Conservation, Construction industry, Graphic methods, Information management, Information theory, Waste disposal, Waste management, Building Information Modelling, Construction wastes, Data analytics, Design optimisation, Minimisation, Big data	Management	Analytics
El-Diraby T.	2017	Automation in Construction	59	10.1016/j.autcon.2017.06.004	BIM-based collaborative design and socio-technical analytics of green buildings	As Building Information Modeling evolves into becoming the central mean for coordinating project design and planning activities, we notice a few limitations/opportunities in the way current BIM tools address the needs for integrated design, collaboration and analysis (the initial objective of BIM). First, substantial communications and interactions about the design exist outside the BIM environment — typically in e-mail formats. This may cause distractions, delays to the project, and could waste valuable knowledge (contained in these interactions). Second, the need of engaging end-users and their keen interest in selecting "green" features. Professionals can develop different designs that achieve varying levels of energy conservation, but these will always require changes based on usage patterns. So, it is important that end-users are involved in the design process early on to make sure that they receive adequate information/ education before they make decisions. This is the nature of limitations that we try to address in this research. This paper builds around the design and development of an online system, named Green2.0 that tries to leverage advancements in Building Information Models (BIM), energy-efficiency simulation tools, and online social network analysis methods to enable a data-driven approach to building planning, construction and maintenance. Fundamentally, it allows participants (end-users or professionals) to comment and share views about building designs. Social network analysis and semantic modeling tools are then used to extract information from these interactions. At the same time, it connects BIM to energy analysis software to allow users to select different products from a catalog and assess the impact of each on energy consumption. The platform aims to advance the current state of the art by bringing about a fundamental shift in the way that AEC professionals, end-users and public policy makers work together throughout a building's lifecycle. Designed as an open platform, it provides access to information that enables researchers and practitioners to build new, more efficient theories and methods of building design. The premise of our work is that by providing new insights into the building design process it is likely to have a profound beneficial effect for both AEC professionals and the society at large. © 2017	This paper builds around the design and development of an online system, named Green2.0 that tries to leverage advancements in Building Information Models (BIM), energy-efficiency simulation tools, and online social network analysis methods to enable a data-driven approach to building planning, construction and maintenance. Fundamentally, it allows participants (end-users or professionals) to comment and share views about building designs.	Social network analysis and semantic modeling tools are then used to extract information from these interactions. At the same time, it connects BIM to energy analysis software to allow users to select different products from a catalog and assess the impact of each on energy consumption.	BIM Collaboration Framework (BCF), Building Information Modeling (BIM), Green building, Industry Foundation Classes (IFC), Socio-technical analytics, Thermal simulation	Buildings, Energy utilization, Design, Energy efficiency, Green2.0 that tries to leverage advancements in Building Information Models (BIM), Industry Foundation Classes - IFC, Sociotechnical, Thermal simulations, Architectural design	Design	BIM
Yin X.	2019	Automation in Construction	54	10.1016/j.autcon.2019.01.010	Building information modelling for off-site construction: Review and future directions	Building Information Modelling (BIM) and off-site construction (OSC) are increasingly applied in the architecture, engineering and construction (AEC) industry due to their many benefits to project stakeholders, such as enhanced design visualization, improved data exchanges, reduced construction waste, improved productivity, and higher product quality. Substantial research efforts have thus been devoted to these topics in recent decades, resulting in a large amount of literature regarding BIM and OSC. This research explores the state-of-the-art in BIM for OSC by means of a bibliometric-qualitative review method. The objective of this research is to uncover the synthesis between BIM and OSC and to identify research trends as well as gaps in knowledge that can be addressed in future research on BIM for OSC. Science maps are constructed by means of bibliometric analysis in order to objectively identify the main research topics of these two fields both separately and jointly based on identified academic publications from Scopus (i.e., 4395 publications on BIM, 2841 publications on OSC, and 113 publications on BIM for OSC). A qualitative review is further conducted on 77 screened research publications (including articles, reviews, conference papers) with a particular focus on BIM for OSC. Through quantitative analysis and in-depth discussion of BIM for OSC, research gaps are identified, and future directions are further proposed as follows: BIM-based generative design for prefabrication, cloud BIM-based data exchange for OSC, robotics and 3D printing for OSC, BIM-enabled big data analytics toward best OSC practice, benefits and its assessment model of BIM for OSC. This research contributes to the body of knowledge by synthesizing the state of the art of BIM for OSC and exposing the research needs in this area in order to improve AEC practice. © 2019 Elsevier B.V.	This research explores the state-of-the-art in BIM for OSC by means of a bibliometric-qualitative review method. The objective of this research is to uncover the synthesis between BIM and OSC and to identify research trends as well as gaps in knowledge that can be addressed in future research on BIM for OSC.	This research contributes to the body of knowledge by synthesizing the state of the art of BIM for OSC and exposing the research needs in this area in order to improve AEC practice.	Bibliometric review, Building information modelling (BIM), In-depth discussion, Literature review, Off-site construction (OSC), Qualitative review	3D printers, Data visualization, Construction, Data Analytics, Electronic data interchange, Information theory, Product design, Publishing, Structural design, Academic publications, Architecture , engineering and construction industries, Bibliometric, Bibliometric analysis, Building Information Modelling, Literature reviews, Off-site construction, Project stakeholders, Architectural design	Design	BIM
Akinade O.O.	2018	Journal of Cleaner Production	52	10.1016/j.jclepro.2018.01.022	Designing out construction waste using BIM technology: Stakeholders' expectations for industry deployment	The need to use Building Information Modelling (BIM) for Construction and Demolition Waste (CDW) minimisation is well documented but most of the existing CDW management tools still lack BIM functionality. This study therefore assesses the expectations of stakeholders on how BIM could be employed for CDW management. After a review of extant literature to assess the limitations of existing CDW management tools, qualitative Focus Group Interviews (FGIs) were conducted with professionals who are familiar with the use of BIM to understand their expectations on the use of BIM for CDW management. The 22 factors identified from the qualitative data analyses were then developed into a questionnaire survey. The exploratory factor analysis of the responses reveals five major groups of BIM expectations for CDW management, which are: (i) BIM-based collaboration for waste management, (ii) waste-driven design process and solutions, (iii) waste analysis throughout building lifecycle, (iv) innovative technologies for waste intelligence and analytics, and (v) improved documentation for waste management. Considering these groups of factors is key to meeting the needs of the stakeholders regarding the use of BIM for CDW management. These groups of factors are important considerations for the implementation and acceptance of BIM-based tools and practices for CDW management within the construction industry. © 2018 The Authors	This study therefore assesses the expectations of stakeholders on how BIM could be employed for CDW management.	The exploratory factor analysis of the responses reveals five major groups of BIM expectations for CDW management, which are: (i) BIM-based collaboration for waste management, (ii) waste-driven design process and solutions, (iii) waste analysis throughout building lifecycle, (iv) innovative technologies for waste intelligence and analytics, and (v) improved documentation for waste management. Considering these groups of factors is key to meeting the needs of the stakeholders regarding the use of BIM for CDW management.	Building information modelling (BIM), Construction and demolition waste, Designing out construction waste, Stakeholders' expectations, Waste minimisation	Architectural design, Charge density waves, Construction industry, Conservation, Construction, Demolition, Design, Factor analysis, Information theory, Surveys, Building Information Modelling, Construction and demolition waste, Construction wastes, Exploratory factor analysis, Innovative technology, Qualitative data analysis, Questionnaire surveys, Waste minimisation, Waste management	Management	BIM
	2014	Research Journal of Applied Sciences, Engineering and Technology	46	10.19026/rjaset.8.1012	BIM in Malaysian construction industry: Status, advantages, barriers and strategies to enhance the implementation level	Building Information Modelling (BIM) is a new approach of construction design. It does not only facilitate the digital representation for designs but also provides all the necessary information for any project before it is constructed. Despite this advantage, the adoption of BIM in Malaysian construction is very low. Motivated by this, current study has focused on assessing current status of BIM implementation in Malaysian construction industry. It has also investigated advantages and disadvantages together with barriers to implementations of BIM and proposing effective strategies for enhancing the BIM implementation in construction industry. Investigation was done through survey where 150 questionnaire forms were distributed and 95 completed forms received back were analyzed with Average Index (AI) and Relative Importance Index (RII) method. Findings of the study revealed that the rate of BIM implementation in construction industry is very low. Major advantages of BIM are improved scheduling, improved drawing coordinated, controlling time and cost and singe detailed model. Enhanced collaboration, requires coordinated drawing, interoperability are the major disadvantages and limitations of BIM. Major barriers to low level of BIM implementation are lack of competent staffto operate the software, unawareness of the technology and non availability of parametric library. Provision of trial software, training of construction staffand introducing of BIM in university curriculum are very effective strategies in enhancing the implementation of BIM. © Maxwell Scientific Organization, 2014.	The current study has focused on assessing current status of BIM implementation in Malaysian construction industry. It has also investigated advantages and disadvantages together with barriers to implementations of BIM and proposing effective strategies for enhancing the BIM implementation in construction industry.	Findings of the study revealed that the rate of BIM implementation in construction industry is very low. Major advantages of BIM are improved scheduling, improved drawing coordinated, controlling time and cost and singe detailed model. Enhanced collaboration, requires coordinated drawing, interoperability are the major disadvantages and limitations of BIM. Major barriers to low level of BIM implementation are lack of competent staffto operate the software, unawareness of the technology and non availability of parametric library	Advantages and disadvantages of BIM, Barriers to implementation, Building information modeling, Malaysian construction industry, Strategies to implement BIM		Analysis	BIM
Lin J.J.	2015	Congress on Computing in Civil Engineering, Proceedings	41	10.1061/9780784479247.020	A framework for model-driven acquisition and analytics of visual data using UAVs for automated construction progress monitoring	Automated assessment of work-in-progress using large collections of site images and 4D BIM has potential to significantly improve the efficiency of construction project controls. Nevertheless, today's manual procedures for taking site photos do not support the desired frequency or completeness for automated progress monitoring. While the usage of Unmanned Aerial Vehicles for acquisition of site images has gained popularity, their application for addressing issues associated with image-based progress monitoring and particularly leveraging 4D BIM for steering the data collection process has not been investigated before. By presenting examples from two case studies conducted on real-world construction projects, this paper suggests a framework for model-driven acquisition and analytics of progress images. In particular, the potential of spatial (geometry, appearance, and interconnectivity) and temporal information in 4D BIM for autonomous data acquisition and analytics that guarantees completeness and accuracy for both as-built modeling and monitoring work-in-progress at the schedule task-level is discussed. © 2015 ASCE.	This paper suggests a framework for model-driven acquisition and analytics of progress images. The usage of Unmanned Aerial Vehicles for acquisition of site images has gained popularity, their application for addressing issues associated with image-based progress monitoring and particularly leveraging 4D BIM for steering the data collection process has not been investigated before.	The potential of spatial (geometry, appearance, and interconnectivity) and temporal information in 4D BIM for autonomous data acquisition and analytics that guarantees completeness and accuracy for both as-built modeling and monitoring work-in-progress at the schedule task-level is discussed	Antennas, Architectural design, Automation, Data acquisition, Project management, Automated assessment, Construction projects, Automated construction, Case-studies, Data collection process, Interconnectivity, Temporal information, Work in progress, Image enhancement		Management	Analytics

Boje C.	2020	Automation in Construction	17	10.1016/j.autcon.2020.103179	Towards a semantic Construction Digital Twin: Directions for future research	As the Architecture, Engineering and Construction sector is embracing the digital age, the processes involved in the design, construction and operation of built assets are more and more influenced by technologies dealing with value-added monitoring of data from sensor networks, management of this data in secure and resilient storage systems underpinned by semantic models, as well as the simulation and optimisation of engineering systems. Aside from enhancing the efficiency of the value chain, such information-intensive models and associated technologies play a decisive role in minimising the lifecycle impacts of our buildings. While Building Information Modelling provides procedures, technologies and data schemas enabling a standardised semantic representation of building components and systems, the concept of a Digital Twin conveys a more holistic socio-technical and prosess-oriented characterisation of the complex artefacts involved by leveraging the synchronicity of the cyber-physical bi-directional data flows. Moreover, BIM lacks semantic completeness in areas such as control systems, including sensor networks, social systems, and urban artefacts beyond the scope of buildings, thus requiring a holistic, scalable semantic approach that factors in dynamic data at different levels. The paper reviews the multi-faceted applications of BIM during the construction stage and highlights limits and requirements, paving the way to the concept of a Construction Digital Twin. A definition of such a concept is then given, described in terms of underpinning research themes, while elaborating on areas for future research. © 2020 The Authors	The paper reviews the multi-faceted applications of BIM during the construction stage and highlights limits and requirements, paving the way to the concept of a Construction Digital Twin.	A Construction Digital Twin definition is given, described in terms of underpinning research themes, while elaborating on areas for future research.	Artificial Intelligence (AI), Big data, BIM, Construction safety, Construction site, Digital Twin, Internet of Things (IoT), Framework, Industry Foundation Classes (IFC), Review	Accident prevention, Architectural design, Big data, Construction industry, Data flow analysis, Digital storage, Information management, Internet of things, Life cycle, Reviews, Semantics, Sensor networks, Construction safety, Construction sites, Framework	Management	AI
Bloch T.	2018	Automation in Construction	34	10.1016/j.autcon.2018.03.018	Comparing machine learning and rule-based inferencing for semantic enrichment of BIM models	The need for extensive pre-processing to prepare model data for sophisticated BIM applications, such as automated code compliance checking, functional simulation and analysis, and information exchange, is a major obstacle to their use. Semantic enrichment offers an alternative, automated approach to manual pre-processing. We illustrate the use of machine learning algorithms for semantic enrichment of BIM models, and compare it to rule-inferencing, through application to the problem of classification of room types in residential apartments. The results showed that machine learning is directly applicable to the space classification problem. Although rule-inferencing has succeeded in other contexts, it proved to be unsuitable for this problem. This leads to the observation that different BIM object classification problems require different approaches. More generally speaking, the AI methods used for semantic enrichment depend on the nature of the problem context, and future research will be needed to establish suitable guidelines. © 2018 Elsevier B.V.	We illustrate the use of machine learning algorithms for semantic enrichment of BIM models, and compare it to rule-inferencing, through application to the problem of classification of room types in residential apartments.	The results showed that machine learning is directly applicable to the space classification problem. Although rule-inferencing has succeeded in other contexts, it proved to be unsuitable for this problem. This leads to the observation that different BIM object classification problems require different approaches. More generally speaking, the AI methods used for semantic enrichment depend on the nature of the problem context, and future research will be needed to establish suitable guidelines	Building information modeling, Machine learning, Semantic enrichment	Artificial intelligence, Compliance control, Learning systems, Automated code, Semantics, Automated approach, Building Information Model - BIM, Functional simulations, Information exchanges, Object classification, Pre-processing, Semantic enrichment, Learning algorithms	Analysis	BIM
Howell S.	2017	Automation in Construction	33	10.1016/j.autcon.2017.02.004	Integrating building and urban semantics to empower smart water solutions	Current urban water research involves intelligent sensing, systems integration, proactive users and data-driven management through advanced analytics. The convergence of building information modeling with the smart water field provides an opportunity to transcend existing operational barriers. Such research would pave the way for demand-side management, active consumers, and demand-optimized networks, through interoperability and a system of systems approach. This paper presents a semantic knowledge management service and domain ontology which support a novel cloud-edge solution, by unifying domestic socio-technical water systems with clean and waste networks at an urban scale, to deliver value-added services for consumers and network operators. The web service integrates state of the art sensing, data analytics and middleware components. We propose an ontology for the domain which describes smart homes, smart metering, telemetry, and geographic information systems, alongside social concepts. This integrates previously isolated systems as well as supply and demand-side interventions, to improve system performance. A use case of demand-optimized management is introduced, and smart home application interoperability is demonstrated, before the performance of the semantic web service is presented and compared to alternatives. Our findings suggest that semantic web technologies and IoT can merge to bring together large data models with dynamic data streams, to support powerful applications in the operational phase of built environment systems. © 2017	This paper presents a semantic knowledge management service and domain ontology which support a novel cloud-edge solution, by unifying domestic socio-technical water systems with clean and waste networks at an urban scale, to deliver value-added services for consumers and network operators.	Our findings suggest that semantic web technologies and IoT can merge to bring together large data models with dynamic data streams, to support powerful applications in the operational phase of built environment systems. © 2017	Big data, BIM, Data analytics, Demand-optimised management, Intelligent sensing, Internet of Things, Semantic web, Interoperability, Ontology, Water management	Architectural design, Automation, Big data, Economics, Electric utilities, Geographic information systems, Intelligent buildings, Internet of things, Interoperability, Knowledge management, Middleware, Ontology, Semantic Web, Waste management, Water management	Management	Analytics
Bilal M.	2015	International Journal of Sustainable Building Technology and Urban Development	28	10.1080/2093761X.2015.1116415	Analysis of critical features and evaluation of BIM software: towards a plug-in for construction waste minimization using big data	The overall aim of this study is to investigate the potential of Building Information Modelling (BIM) for construction waste minimization. We evaluated the leading BIM design software products and concluded that none of them currently support construction waste minimization. This motivates the development of a plug-in for predicting and minimizing construction waste. After a rigorous literature review and conducting four focused group interviews (FGIs), 12 imperative BIM factors were identified that should be considered for predicting and designing out construction waste. These factors were categorized into four layers, namely the BIM core features layer, the BIM auxiliary features layer, the waste management criteria layer, and the application layer. Further, a process to carry out BIM-enabled building waste analysis (BWA) is proposed. We have also investigated the usage of big data technologies in the context of waste minimization. We highlight that big data technologies are inherently suitable for BIM due to their support of storing and processing large datasets. In particular, the use of graph-based representation, analysis, and visualization can be employed for advancing the state of the art in BIM technology for construction waste minimization. © 2016 Taylor & Francis.	The overall aim of this study is to investigate the potential of Building Information Modelling (BIM) for construction waste minimization. We evaluated the leading BIM design software products and concluded that none of them currently support construction waste minimization.	We highlight that big data technologies are inherently suitable for BIM due to their support of storing and processing large datasets. In particular, the use of graph-based representation, analysis, and visualization can be employed for advancing the state of the art in BIM technology for construction waste minimization.	big data analytics, BIM, construction waste prediction and minimization, design out waste, NoSQL systems, waste prevention	computer aided design, software, construction, data set, waste management	Management	BIM
Barone D.	2010	Lecture Notes in Business Information Processing	26	10.1007/978-3-642-16782-9_3	Enterprise modelling for business intelligence	Business Intelligence (BI) software aims to enable business users to easily access and analyze relevant enterprise information so that they can make timely and fact-based decisions. However, despite user-friendly features such as dashboards and other visualizations, business users still find BI software hard to use and inflexible for their needs. Furthermore, current BI initiatives require significant efforts by IT specialists to understand business operations and requirements, in order to build BI applications and help formulate queries. In this paper, we present a vision for BI that is driven by enterprise modeling. The Business Intelligence Model (BIM) aims to enable business users to conceptualize business operations and strategies and performance indicators in a way that can be connected to enterprise data through highly automated tools. The BIM draws upon well-established business practices such as Balanced Scorecard and Strategy Maps as well as requirements and conceptual modeling techniques such as goal modeling. The connection from BIM to databases is supported by a complementary research effort on conceptual data integration. © 2010 IFIP International Federation for Information Processing.	The Business Intelligence Model (BIM) aims to enable business users to conceptualize business operations and strategies and performance indicators in a way that can be connected to enterprise data through highly automated tools.	The BIM draws upon well-established business practices such as Balanced Scorecard and Strategy Maps as well as requirements and conceptual modeling techniques such as goal modeling. The connection from BIM to databases is supported by a complementary research effort on conceptual data integration. © 2010 IFIP International Federation for Information Processing.	Analytics, Business Intelligence, Conceptual Modeling, Enterprise Modeling, Key Performance Indicators, Strategic Planning	Benchmarking, Competitive intelligence, Industry, Visualization, Data integration, Data mining, Information analysis, Analytics, Business Intelligence, Conceptual modeling, Enterprise modeling, Key performance indicators, Balanced scorecards, Business operation, Business practices, Conceptual model, Performance indicators, Strategic planning	Analysis	BIM
Dibowski H.	2017	Proceedings - SIMS 2016: 2nd International Conference on Systems Informatics, Modelling and Simulation	18	10.1109/SIMS.2016.22	Knowledge-Based Fault Propagation in Building Automation Systems	This paper describes a knowledge-based approach that can reason about effects of faults and causes of abnormal situations in building automation systems (BAS). Combining an ontology-based building information model (BIM), which models a BAS formally and semantically, with rules encoding expert knowledge, the fault propagation approach can automatically determine causalities in BAS and propagate faults along the causalities in both forward and backward direction. This enables an immediate assessment of potential consequences of faults respectively an analysis of the root cause(s). The fault propagation approach can enhance fault detection and diagnosis by considering BAS as a whole, being aware of the potentially far reaching consequences of faults, instead of just focusing on single pieces of equipment or zones. This provides a better understanding of BAS and improves the decision making and prioritization of the right emergency and maintenance actions. © 2016 IEEE.	This paper describes a knowledge-based approach that can reason about effects of faults and causes of abnormal situations in building automation systems (BAS).	The fault propagation approach can enhance fault detection and diagnosis by considering BAS as a whole, being aware of the potentially far reaching consequences of faults, instead of just focusing on single pieces of equipment or zones. This provides a better understanding of BAS and improves the decision making and prioritization of the right emergency and maintenance actions. © 2016 IEEE.	building automation system analytics, building information model, fault detection, fault propagation and diagnosis, knowledge-based systems, ontology, Buildings, rules	Architectural design, Automation, Decision making, Drug products plants, Enterprise resource planning, Information and theory, Intelligent buildings, Knowledge based systems, Ontology, Building automation systems, Building Information Model - BIM, Fault detection and diagnosis, Fault propagation, Forward-and-backward, Knowledge-based approach, Maintenance Action, rules	Design	Analytics
Marzouk M.	2019	Automation in Construction	16	10.1016/j.autcon.2018.11.018	Text analytics to analyze and monitor construction project contract and correspondence	Text mining is a fast-growing area of research, due to its ability to discover valuable information and getting insights hidden in plain texts. The aim of this paper is to apply text mining in order to analyze construction project contracts and visually analyze project correspondence. Analyzing construction contract helps project parties to figure out their obligations and reduce time and effort needed for contract analysis. Additionally, performing text mining to the contract helps in extracting critical keywords that should be monitored closely in the correspondence. On the other hand, applying text mining for project correspondence helps in gaining an understanding regarding the communication nature and sentiment between project parties. Thus, the paper develops a Dynamic Text Analytical model for Contract and Correspondence "DTA-CC" through utilizing BIM. The DTA-CC model assists project parties to explore texts and get insights regarding the project performance. The specific objectives of this study are to 1- perform a text analytics of the construction project contract, 2- integrate project correspondence within the BIM model and 3- develop a text analytical model based on project's correspondence to monitor the project performance. The DTA-CC model is validated by applying a case study for a construction project located in Cairo, Egypt. The case study found that there is a lot of hidden information in the project's raw data. Moreover, it is crucial to monitor raw data in order to achieve a successful project. This study extends the existing knowledge by proposing a novel methodology to extract meaningful patterns from construction projects data. © 2018 Elsevier B.V.	The aim of this paper is to apply text mining in order to analyze construction project contracts and visually analyze project correspondence.	The case study found that there is a lot of hidden information in the project's raw data. Moreover, it is crucial to monitor raw data in order to achieve a successful project. This study extends the existing knowledge by proposing a novel methodology to extract meaningful patterns from construction projects data. © 2018 Elsevier B.V.	BIM, Construction industry, Text mining, Text visualization	Analytical models, Architectural design, Construction industry, Hidden information, Construction contract, Construction projects, Novel methodology, Project performance, Text analytics, Text mining, Text visualization, Data mining	Design	Analytics
Ding K.	2018	ICNSC 2018 - 15th IEEE International Conference on Networking, Sensing and Control	16	10.1109/ICNSC.2018.8361339	Smart steel bridge construction enabled by BIM and Internet of Things in Industry 4.0: A Framework	To deal with the uncontrollability and inefficiency problem of construction progress, quality, and cost in traditional steel bridge construction projects, this paper discusses smart steel bridge construction enabled by Building Information Modeling (BIM) and Internet of Things (IoT). The framework of smart steel bridge construction is firstly proposed. The research directions and roadmap are further pointed out. The core idea of smart steel bridge construction is to apply data-driven methods and model-based analytics to realize real-time collaborative management and closed-loop control of steel bridge lifecycle activities. It is expected that this paper will position the BIM- and IoT-enabled steel bridge construction mode in the context of industry 4.0. © 2018 IEEE.	this paper discusses smart steel bridge construction enabled by Building Information Modeling (BIM) and Internet of Things (IoT). The framework of smart steel bridge construction is firstly proposed. The research directions and roadmap are further pointed out.	It is expected that this paper will position the BIM- and IoT-enabled steel bridge construction mode in the context of industry 4.0. © 2018 IEEE.	Building Information Modeling (BIM), Industry 4.0, Internet of Things (IoT), Smart construction, Steel bridge	Construction, Industry 4.0, Steel bridges, Information theory, Internet of things, Building Information Model - BIM, Closed-loop control, Construction progress, Data-driven methods, Internet of Things (IOT), Life cycle activities, Real-time collaborative, Steel bridge construction, Architectural design	Design	BIM
Aziz Z.	2017	Facilities	16	10.1108/F-02-2016-0021	Leveraging BIM and Big Data to deliver well maintained highways	Purpose: Effective management of highways requires management of diverse data sets including traffic volume data, roadway and road edge and road-side data. Like all major infrastructure clients, highways administration authorities are under pressure to use such platforms for better management of data that, in addition to creating other opportunities, allows improved life cycle management of asset data and predictive analytics. This paper aims to review such opportunities and the value that can be generated through integrated life cycle data management by leveraging Big Data and building information modelling (BIM). Design/methodology/approach: A literature review is initially performed to systematically gather information to identify and understand BIM as a collaborative platform. Data management applications in other industries are also reviewed. Interviews were conducted and two industry workshops were organised to understand BIM implementation challenges within highways development projects and the role BIM can play in bridging inefficiencies resulting from loss of information at handover phases. The overall understanding lead to drawing up user needs, gathering system requirements and eventually a system architecture design to promote efficient information management throughout the asset lifecycle. Findings: It is observed that data from the design and construction phases of projects can be used to inform asset registers from an earlier stage. This information can be used to plan maintenance schedules. Moreover, it can also be integrated with data generated from numerous other sensors to develop a better picture of network operations and support key decision-making. Effective road network management involves collection and analysis of huge data from a variety of sources including sensors, mobiles, assets and Open Data. Recent growth in Big Data analytics and data integration technologies provides new opportunities to optimise operations of highways infrastructure. Research limitations/implications: The system architecture designed for this research is translated into a prototype system as a proof of concept. However, it needs to be tested and validated by end users to be transformed into a useful solution for the industry. Originality/value: This paper provides an enhanced understanding of new opportunities created to optimise operations of highways infrastructure using the recent growth in Big Data analytics and data integration technologies. © 2017, © Emerald Publishing Limited.	This paper aims to review such opportunities and the value that can be generated through integrated life cycle data management by leveraging Big Data and building information modelling (BIM).	This paper provides an enhanced understanding of new opportunities created to optimise operations of highways infrastructure using the recent growth in Big Data analytics and data integration technologies. © 2017, © Emerald Publishing Limited.	Asset management, Big Data, BIM, Data management, Facilities management, Highways management		Management	BIM

Khoja M.	2016	Procedia Engineering	16	10.1016/j.proeng.2016.04.072	Optimizing BIM Metadata Manipulation Using Parametric Tools	Building Information Management (BIM) is gaining popularity in the AEC industry for design and construction. Moving into the operations phase of the building, non-geometric information such as indoor environmental quality, and essential building services become increasingly important. The cost of maintaining the information in the BIM model has been a historical obstacle to adoption of BIM during this phase. To overcome this barrier, parametric tools such as Dynamo - often used for developing and manipulating model geometry - have been used to automate the information transfer between the BIM models and facilities management systems. This paper presents a case study investigating this technique, including series of investigations using parametric design tools, APIs and macros to classify, format, manipulate, and assign operations information to BIM elements. This case study demonstrates significant potential for automatic population of this non-geometric data into BIM models and the subsequent improvement for adoption of BIM in the operations phase. © 2016 The Authors.	This paper presents a case study investigating this technique, including series of investigations using parametric design tools, APIs and macros to classify, format, manipulate, and assign operations information to BIM elements.	This case study demonstrates significant potential for automatic population of this non-geometric data into BIM models and the subsequent improvement for adoption of BIM in the operations phase. © 2016 The Authors.	analytics, Building Information Management, Building Information Modeling, building operations, Facilities Management, parametric tools, Flow visualization, visualization	Buildings, Classification (of information), Geometry, Information management, Population statistics, Structural design, Sustainable development, analytics, Building Information Model - BIM, Building operations, Design and construction, Facilities management, Facilities management system, Indoor environmental quality, Parametric design tools, Architectural design	Management	BIM
Wu B.	2016	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives	16	10.5194/isprsarchives-XLI-B2-455-2016	Integration of GIS And BIM for indoor geovisual analytics	This paper presents an endeavour of integration of GIS (Geographical Information System) and BIM (Building Information Modelling) for indoor geovisual analytics. The merits of two types of technologies, GIS and BIM are firstly analysed in the context of indoor environment. GIS has well-developed capabilities of spatial analysis such as network analysis, while BIM has the advantages for indoor 3D modelling and dynamic simulation. This paper firstly investigates the important aspects for integrating GIS and BIM. Different data standards and formats such as the IFC (Industry Foundation Classes) and GML (Geography Markup Language) are discussed. Their merits and limitations in data transformation between GIS and BIM are analysed in terms of semantic and geometric information. An optimized approach for data exchange between GIS and BIM datasets is then proposed. After that, a strategy of using BIM for 3D indoor modelling, GIS for spatial analysis, and BIM again for visualization and dynamic simulation of the analysis results is presented. Based on the developments, this paper selects a typical problem, optimized indoor emergency evacuation, to demonstrate the integration of GIS and BIM for indoor geovisual analytics. The block Z of the Hong Kong Polytechnic University is selected as a test site. Detailed indoor and outdoor 3D models of the block Z are created using a BIM software Revit. The 3D models are transferred to a GIS software ArcGIS to carry out spatial analysis. Optimized evacuation plans considering dynamic constraints are generated based on network analysis in ArcGIS assuming there is a fire accident inside the building. The analysis results are then transferred back to BIM software for visualization and dynamic simulation. The developed methods and results are of significance to facilitate future development of GIS and BIM integrated solutions in various applications.	This paper presents an endeavour of integration of GIS (Geographical Information System) and BIM (Building Information Modelling) for indoor geovisual analytics. This paper firstly investigates the important aspects for integrating GIS and BIM. Different data standards and formats such as the IFC (Industry Foundation Classes) and GML (Geography Markup Language) are discussed.	The analysis results are then transferred back to BIM software for visualization and dynamic simulation. The developed methods and results are of significance to facilitate future development of GIS and BIM integrated solutions in various applications.	Computer software, Electronic data interchange, Geographic information systems, Integration, Markup languages, Mathematical transformations, Semantics, Metadata, Remote sensing, Spatial variables measurement, Three dimensional computer graphics, Visualization, Building Information Modelling, Data transformation, Emergency evacuation, Geometric information, GML (geography markup language), Industry Foundation Classes - IFC, Integrated solutions, Optimized evacuation, Architectural design		Analysis	BIM
Akinade O.O.	2019	Journal of Cleaner Production	14	10.1016/j.jclepro.2019.04.232	Integrating construction supply chains within a circular economy: An ANFIS-based waste analytics system (A-WAS)	The circular economy agenda makes it paramount for construction supply chains to reduce material waste. Although a collaborative platform called Building Information Modelling (BIM) offers a means of supply chains integration, it has not been efficiently upscaled for delivering waste efficient building designs. This study, therefore, develops a BIM-based computational tool for building waste analytics and reporting in the construction supply chains. A Construction Waste (CW) prediction model using Adaptive Neuro-Fuzzy Inference System (ANFIS) was developed and integrated into Autodesk Revit BIM platform. The model development process reveals that "Gross Floor Area" and "Construction type" are the two key predictors for CW. The results of the study show that the tool offers useful insights into CW minimisation opportunities. The study makes a huge contribution to CW management practices by developing a computational approach to CW measurement. The contribution of the study is fundamental because achieving accurate waste prediction is crucial to waste prevention through adequate design principles and BIM. © 2019	This study, therefore, develops a BIM-based computational tool for building waste analytics and reporting in the construction supply chains. A Construction Waste (CW) prediction model using Adaptive Neuro-Fuzzy Inference System (ANFIS) was developed and integrated into Autodesk Revit BIM platform.	The results of the study show that the tool offers useful insights into CW minimisation opportunities. The study makes a huge contribution to CW management practices by developing a computational approach to CW measurement. The contribution of the study is fundamental because achieving accurate waste prediction is crucial to waste prevention through adequate design principles and BIM. © 2019	Building information modelling (BIM), Circular economy, Construction supply chains, Construction waste analytics, Predictive modelling	Computational methods, Construction, Fuzzy systems, Fuzzy inference, Fuzzy neural networks, Information theory, Predictive analytics, Supply chains, Building Information Modelling, Circular economy, Construction supply chain, Construction wastes, Predictive modelling, Architectural design	Design	Analytics
Ciribini A.L.C.	2017	Procedia Engineering	13	10.1016/j.proeng.2017.04.311	Tracking Users' Behaviors through Real-time Information in BIMs: Workflow for Interconnection in the Brescia Smart Campus Demonstrator	An intelligent building supports the needs of its occupants by data analytics. Nowadays, buildings are evolving from being products to become effective service providers for end-users: thus, occupancy topics become crucial. The paper focuses on building operations, pointing out how advantages in supporting the needs of users could be derived through the implementation of Building Management Systems (BMS) into a Building Information Modelling (BIM) environment, connecting real-time information collected by sensors to a BIM database. The connection and the integration of information between BIM and BMS have been established based on the Industry Foundation Classes (IFC) neutral data format	The paper focuses on building operations, pointing out how advantages in supporting the needs of users could be derived through the implementation of Building Management Systems (BMS) into a Building Information Modelling (BIM) environment, connecting real-time information collected by sensors to a BIM database.	An intelligent building supports the needs of its occupants by data analytics. Nowadays, buildings are evolving from being products to become effective service providers for end-users: thus, occupancy topics become crucial.	Behavioural Modelling Building Information Modelling, Building Management Systems, Intelligent Building, Interoperability	Buildings, Intelligent buildings, Information management, Information theory, Interoperability, Real time systems, Behavioural modelling, Building Information Model - BIM, Building Information Modelling, Building management system, Building operations, Industry Foundation Classes - IFC, Neutral data formats, Real-time information, Architectural design	Management	BIM
Rinaldi S.	2016	IEEE 2nd International Smart Cities Conference: Improving the Citizens Quality of Life, ISC2 2016 - Proceedings	13	10.1109/ISC2.2016.7580819	Bi-directional interactions between users and cognitive buildings by means of smartphone app	The new relationship between users and assets through mobile service is changing the way to deliver services by smart devices. The research developed for the project SCUOLA - Smart Campus as Urban Open LAb introduced the idea of creating an app to include the users' feedback into the information chain of a pilot smart building. The paper describes the early-stage of implementation and evolution of this concept, which define a dialogue between building and users, by realizing a bi-directional interaction via a newly developed mobile application. The app - Smart Campus UNIBS - mediates, as part of a complex system, between the two entities using the connectivity of Smart Living and the process of Data Analytics. The Smart Campus Demonstrator building at the University of Brescia, Italy, is equipped with sensors to monitor and control comfort, indoor air quality and HVAC parameters, such as hygro-thermal parameters, illuminance, CO2 and volatile organic compound (VOC), power of HVAC fans and environmental external factors. The sensors aim at providing data to develop adaptive, dynamic as well as predictive controls virtually incrementing the smartness of the building. The step further is to include the behavioral perspective linking the users to the previous framework. By exchanging different kinds of processed data, including BIM models, sensors and user feedbacks, it is possible to achieve an interaction between the built environment and the social landscape. The Smart Campus Demonstrator building integrates the smart concepts involved in the SCUOLA research project and beyond. It has been chosen to reveal the potential of such reciprocal interchange between humans and constructions towards the extended smart city. The overall purpose is ultimately that of creating a prototype for adaptive systems in architecture i.e. "Cognitive Buildings" which can learn by users' behavior. © 2016 IEEE.	The paper describes the early-stage of implementation and evolution of this concept, which define a dialogue between building and users, by realizing a bi-directional interaction via a newly developed mobile application. The app - Smart Campus UNIBS - mediates, as part of a complex system, between the two entities using the connectivity of Smart Living and the process of Data Analytics.	The Smart Campus Demonstrator building integrates the smart concepts involved in the SCUOLA research project and beyond. It has been chosen to reveal the potential of such reciprocal interchange between humans and constructions towards the extended smart city. The overall purpose is ultimately that of creating a prototype for adaptive systems in architecture i.e. "Cognitive Buildings" which can learn by users' behavior. © 2016 IEEE.	Behavioral servitization, Bi-directional app, Cognitive building, Smart cities, Users-responsive building	Air quality, Architectural design, Indoor air pollution, Cognitive systems, Data Analytics, Mobile telecommunication systems, Quality control, Smart city, Volatile organic compounds, Bi-directional, Bi-directional interaction, Indoor air quality, Mobile applications, Monitor and control, Servitization, Thermal parameters, Volatile organic compound (VOC), HVAC	Design	Analytics
Li D.	2018	Automation in Construction	12	10.1016/j.autcon.2018.02.002	Integrating geometric models, site images and GIS based on Google Earth and Keyhole Markup Language	Technologies for information management and visualization are instrumental in enhancing human perceptions and interpretations of complicated project information. 3D/4D modeling, Virtual Reality (VR), Building Information Models (BIM) and Geographical Information Systems (GIS) have been increasingly used for data management and analytics in construction. Apart from virtual models, it is essential to represent the ever-changing site reality by integrating images captured with drones, mobile devices, and digital cameras. To improve the cognitive perception of the site environment from fragmented datasets, this paper proposes a framework to integrate unordered images, geometric models and surrounding environment in Google Earth using Keyhole Markup Language (KML). A ground-control-free methodology to geo-reference sequential aerial imageries and ground imageries is proposed in order to place unordered images into the physical coordinate system of Google Earth. To combine geometric models, site images and panoramic images with the site surrounding environment in 3D GIS, a KML and cloud storage based data management system is conceptualized to handle large scale datasets. The research provides construction engineers with a low-cost and low-technology-barrier solution to represent a dynamic construction site through information management, integration and visualization. © 2018 Elsevier B.V.	this paper proposes a framework to integrate unordered images, geometric models and surrounding environment in Google Earth using Keyhole Markup Language (KML). A ground-control-free methodology to geo-reference sequential aerial imageries and ground imageries is proposed in order to place unordered images into the physical coordinate system of Google Earth.	The research provides construction engineers with a low-cost and low-technology-barrier solution to represent a dynamic construction site through information management, integration and visualization. © 2018 Elsevier B.V	Augmented reality, Google earth, Information, Integration, KML, Visualization	Aerial photography, Augmented reality, Antennas, Architectural design, Digital devices, Digital storage, Flow visualization, Geographic information systems, Geometry, Image enhancement, Integration, Markup languages, Rock mechanics, Virtual reality, Visualization, Building Information Model - BIM, Construction engineers, Data management system, Google earths	Management	AI
Oreni D.	2017	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives	11	10.5194/isprs-Archives-XLII-5-W1-107-2017	Survey, HBIM and conservation plan of a monumental building damaged by earthquake	"Surveying a monumental building damaged by the earthquake means to analyze its geometries, the structural elements, the connection still exist between the different parts, in order to define its state of conservation, to make structural analysis and to plan a proper project of restoration, consolidation, seismic improvement or addition of new elements. The survey of structural geometry represents the first necessary moment of building' knowledge investigation, to be performed after the securing of the building by the Firefighters or Civil Protection. How and by which instruments the geometric analysis are conducted depends on many factors, not always exclusively on the will of the experts involved in the restoration project, but more often dictated by political, technical, social or economic needs. The accurate geometrical survey is referred as fundamental operation even by national Directive for evaluation and earthquake risk reduction of cultural heritage (GU n. 24 - 29/01/2008 and 2011 updates), which defines guidelines for preventive interventions on built heritage in order to make the structures less vulnerable in case of earthquake. Nowadays, the wide use of tools and accurate surveying techniques makes it possible to achieve an adequate level of accuracy of information related to the buildings, overcoming the difficulties due to accessibility of the damaged structures. The geometrical survey of the Basilica of Santa Maria di Collemaggio in L'Aquila, was made by Politecnico di Milano starting from 2013, within the project ""Ripartire da Collemaggio"" (http://www.ungiornoacollemaggio.it/content/2027), financed by Eni.versi.it. The basilica, an important symbol for the community of L'Aquila, was gravely damaged by the earthquake of 6th April 2009. The objective of Eni was to turn the restoration of the building in a re-birth moment for all the community. The knowledge step was aimed to plan a restoration project able of returning the basilica to a safe and full use. In the two years knowledge investigation steps (geometric survey, historical and stratigraphic analysis, materials investigation, structures and soils examination, in situ tests and numerical elaborations) was involved an interdisciplinary group of researchers from various Italian universities, Politecnico di Milano, Università La Sapienza in Rome and the University of L'Aquila, called to provide a scientific advice to the Soprintendenza ai Beni Architettonici e Paesaggistici per l'Abruzzo, project manager of the restoration step. In early 2016 the yard of restoration was opened and it is still on-going. The geometrical survey of the basilica was aim to investigate, measure and represent the exact geometry of the damaged structures and their three-dimensional complexity the survey was planned choosing the tools and methods most appropriate in relation with the accessibility and safety of the structures, the operating ranges of acquisition and the level of detail required by the analysis and the project. This meant to integrate global and local surveying techniques, in order to cross relate data derived by different tools and to make the graphical restitution of the entire monumental complex: Topography, laser scanning, photogrammetry, but also hands on instruments, at a scale of representation from 1:1 to 1:50. The laser scanner survey, registered in the accurate geomatics network, responded to the need to punctually investigate and interpret the geometrical configuration of different spaces of the Basilica, as well as its structural articulation, enabling a series of horizontal and vertical profiles, as requested by various experts involved in the diagnostic steps. HBIM model (Historical Building Information Modeling) of the entire basilica was primarily intended as a tool for stereotomic elements, sometimes it has been used stratigraphic methodologies and instruments of analysis. The entirety of the geometric and structural complexity of the basilica, was guarantee using sophisticated 3D software and drawing complex entities, integrated and stored in the parametric BIM logic. This process has allowed to accurately and timely represent the geometry of the structural elements, of the areas characterized by crushing, empties, variations of the masonry sections and out of plumbs.	Integrate surveying techniques, in order to cross relate data derived by different tools and to make the graphical restitution of the entire monumental complex: Topography, laser scanning, photogrammetry, but also hands on instruments, at a scale of representation from 1:1 to 1:50. The laser scanner survey, registered in the accurate geomatics network, responded to the need to punctually investigate and interpret the geometrical configuration of different spaces of the Basilica, as well as its structural articulation, enabling a series of horizontal and vertical profiles, as requested by various experts involved in the diagnostic steps. HBIM model (Historical Building Information Modeling) of the entire basilica was primarily intended as a tool for stereotomic elements, sometimes it has been used stratigraphic methodologies and instruments of analysis. The entirety of the geometric and structural complexity of the basilica, was guarantee using sophisticated 3D software and drawing complex entities, integrated and stored in the parametric BIM logic. This process has allowed to accurately and timely represent the geometry of the structural elements, of the areas characterized by crushing, empties, variations of the masonry sections and out of plumbs.	The main principles and criteria of restoration were: maximum correspondence of conservation doctrine, with a focus on improving the structural characteristics compared to the seismic risk exemplarity of the management practices of the restoration process exemplarity of innovative techniques transparency of all processes and accurate communication of cultural and scientific content. Despite of some inevitable compromises, the detailed knowledge of the building allowed to design punctual interventions, inserting new structures where the oldest were collapsed and consolidating damaged elements, in order to improve the global safety of the building but without modifying substantially the structural conception of the stratified basilica.	Conservation project, Earthquake, HBIM, Structural geometry, Survey	Architectural design, Authentication, College buildings, Brick buildings, Buildings, Complex networks, Composite structures, Computer circuits, Conservation, Earthquakes, Geometry, Geophysics, Laser applications, Religious buildings, Restoration, Safety engineering, Seismology, Stratigraphy, Structural analysis, Surveying	Management	BIM
Schultz C.	2013	Procedia Computer Science	11	10.1016/j.procs.2013.05.171	IoSpaces3D: A middleware for built-environment data access and analytics	Standardisation, archiving, and digital access of spatial data pertaining to built-up environments is an area acquiring increasing attention amongst several interest groups: policy makers, designers and planners, civil engineers, infrastructure management and public service personnel, building users. Initiatives such as the Building Information Model (BIM), Industry Foundation Classes (IFC), and CityGML are creating the information-theoretic backbone that guides the crucial aspects of quality, exchange, and interoperability of spatial data at the environmental and urban scale. However, due to the inherent scale, complexity, and detailed geometric character of building information data, extracting useful semantic and qualitative knowledge for accomplishing high-level analytical tasks is still an extremely complex and error prone process involving data intensive computing. We propose a uniform spatial data access middleware that can provide a combination of high-level, multi-modal, semantic, and quantitative-qualitative spatial data access and analytical capability. We present the core computational capabilities for the proposed middleware and present an overview of the high-level spatial model and its compliance with the industry standard IFC. A key theoretical contribution is a framework for investigating the computational complexity of deriving spatial artefacts within the context of building informatics. Additionally, we empirically investigate the feasibility and practicality of the derivation of spatial artefacts by conducting experiments on seven industry-scale IFC models. The experiment results show that, despite having non-linear polynomial increase with respect to time, deriving spatial artefacts is practical with large designs. © 2013 The Authors. Published by Elsevier B.V.	We propose a uniform spatial data access middleware that can provide a combination of high-level, multi-modal, semantic, and quantitative-qualitative spatial data access and analytical capability. We present the core computational capabilities for the proposed middleware and present an overview of the high-level spatial model and its compliance with the industry standard IFC.	he experiment results show that, despite having non-linear polynomial increase with respect to time, deriving spatial artefacts is practical with large designs. © 2013 The Authors. Published by Elsevier B.V.	Architecture, Artificial intelligence, Building information model, Spatial analysis		Analysis	Analytics

Xivi Q.L.	2019	International Conference on Smart Infrastructure and Construction 2019, ICSIC 2019: Driving Data-informed Decision-Making	10	10.1680/icsic.64668.067	Developing a dynamic digital twin at a building level: Using Cambridge campus as case study	A Digital Twin (DT) refers to a digital replica of physical assets, processes and systems. DTs integrate artificial intelligence, machine-learning and data analytics to create dynamic digital models that are able to learn and update the status of the physical counterpart from multiple sources. A DT, if equipped with appropriate algorithms will represent and predict future condition and performance of their physical counterparts. Current developments related to DTs are still at an early stage with respect to buildings and other infrastructure assets. Most of these developments focus on the architectural and engineering/construction point of view. Less attention has been paid to the operation & maintenance (O&M) phase, where the value potential is immense. A systematic and clear architecture verified with practical use cases for constructing a DT is the foremost step for effective operation and maintenance of assets. This paper presents a system architecture for developing dynamic DTs in building levels for integrating heterogeneous data sources, support intelligent data query, and provide smarter decision-making processes. This will further bridge the gaps between human relationships with buildings/regions via a more intelligent, visual and sustainable channels. This architecture is brought to life through the development of a dynamic DT demonstrator of the West Cambridge site of the University of Cambridge. Specifically, this demonstrator integrates an as-is multi-layered IFC Building Information Model (BIM), building management system data, space management data, real-time Internet of Things (IoT)-based sensor data, asset registry data, and an asset tagging platform. The demonstrator also includes two applications: (1) improving asset maintenance and asset tracking using Augmented Reality (AR) and (2) equipment failure prediction. The long-term goals of this demonstrator are also discussed in this paper. © International Conference on Smart Infrastructure and Construction 2019, ICSIC 2019: Driving Data-informed Decision-Making.	This paper presents a system architecture for developing dynamic DTs in building levels for integrating heterogeneous data sources, support intelligent data query, and provide smarter decision-making processes. This will further bridge the gaps between human relationships with buildings/regions via a more intelligent, visual and sustainable channels.This architecture is brought to life through the development of a dynamic DT demonstrator of the West Cambridge site of the University of Cambridge.	The demonstrator also includes two applications: (1) improving asset maintenance and asset tracking using Augmented Reality (AR) and (2) equipment failure prediction. The long-term goals of this demonstrator are also discussed in this paper. © International Conference on Smart Infrastructure and Construction 2019, ICSIC 2019: Driving Data-Informed Decision-Making.	Architectural design Artificial intelligence, Augmented reality, Data Analytics, Decision making, Intelligent buildings, Digital twin, Dynamics, Maintenance, Memory architecture, Search engines, Building information Model - BIM, Building management system, Decision making process, Equipment failure predictions, Heterogeneous data sources, Infrastructure assets, Operation and maintenance, University of Cambridge, Information management		Management	AI
Yarmohammadi S.	2018	Automation in Construction	10	10.1016/j.autcon.2018.05.011	Automated performance measurement for 3D building modeling decisions	Building information modeling (BIM) is instrumental in documenting design, enhancing customer experience, and improving product functionality in capital projects. However, high-quality building models do not happen by accident, but rather because of a managed process that involves several participants from different disciplines and backgrounds. Throughout this process, the different priorities of design modelers often result in conflicts that can negatively impact project outcomes. To prevent such unwanted outcomes from occurring, the modeling process needs to be effectively managed. This effective management requires an ability to closely monitor the modeling process and correctly measure the modelers' performance. Nevertheless, existing methods of performance monitoring in building design practices lack an objective measurement system to quantify modeling progress. The widespread utilization of BIM tools presents a unique opportunity to retrieve granular design process data and conduct accurate performance measurements. This research improves upon previous efforts by presenting a novel application programming interface (API)-enabled approach to (a) automatically collect detailed model development data directly from BIM software packages in real-time, and (b) efficiently calculate several modeling performance measures during schematic and design development phases of building projects. These indicators can be used to properly arrange modeling teams in the quest for high-quality building models. The specific objectives of this study to examine the feasibility of a proposed automated design performance measurement framework, and to identify optimal modeling team configurations using empirical performance information. A passive data recording approach allows for the real-time capture of comprehensive user interface (UI) interaction and model element modification events. The proposed framework is implemented as an Autodesk Revit plugin. Next, an experiment is conducted to capture data using the developed Revit plugin. Experiment participants' individual production rates are estimated to establish the validity of the proposed approach to identify the optimal design team configuration. The presented approach uses the earliest due date (EDD) sequencing rule in combination with the critical path method (CPM) to calculate the maximum lateness for different design team arrangements. © 2018 Elsevier B.V.	This research improves upon previous efforts by presenting a novel application programming interface (API)-enabled approach to (a) automatically collect detailed model development data directly from BIM software packages in real-time, and (b) efficiently calculate several modeling performance measures during schematic and design development phases of building projects.	The presented approach uses the earliest due date (EDD) sequencing rule in combination with the critical path method (CPM) to calculate the maximum lateness for different design team arrangements. © 2018 Elsevier B.V.	Application programming interface, BIM, Data analytics, Modeling team, Performance measurement	Application programming interfaces (API), Application programs, Turnaround time, Product design, Project management, User interfaces, Accurate performance, Building Information Model - BIM, Data analytics, Empirical performance, Modeling team, Objective measurement, Performance measurements, Performance monitoring, Architectural design	Management	BIM
Pan Y.	2021	Automation in Construction	9	10.1016/j.autcon.2020.103517	Roles of artificial intelligence in construction engineering and management: A critical review and future trends	With the extensive adoption of artificial intelligence (AI), construction engineering and management (CEM) is experiencing a rapid digital transformation. Since AI-based solutions in CEM has become the current research focus, it needs to be comprehensively understood. In this regard, this paper presents a systematic review under both scientometric and qualitative analysis to present the current state of AI adoption in the context of CEM and discuss its future research trends. To begin with, a scientometric review is performed to explore the characteristics of keywords, journals, and clusters based on 4,473 journal articles published in 1997–2020. It is found that there has been an explosion of relevant papers especially in the past 10 years along with the change in keyword popularity from expert systems to building information modeling (BIM), digital twins, and others. Then, a brief understanding of CEM is provided, which can be benefited from the emerging trend of AI in terms of automation, risk mitigation, high efficiency, digitalization, and computer vision. Special concerns have been put on six hot research topics that amply the advantage of AI in CEM, including (1) knowledge representation and reasoning, (2) information fusion, (3) computer vision, (4) natural language processing, (5) intelligence optimization, and (6) process mining. The goal of these topics is to model, predict, and optimize issues in a data-driven manner throughout the whole lifecycle of the actual complex project. To further narrow the gap between AI and CEM, six key directions of future researches, such as smart robotics, cloud virtual and augmented reality (cloud VR/AR), Artificial Intelligence of Things (AIoT), digital twins, 4D printing, and blockchains, are highlighted to constantly facilitate the automation and intelligence in CEM. © 2020 Elsevier B.V.	this paper presents a systematic review under both scientometric and qualitative analysis to present the current state of AI adoption in the context of CEM and discuss its future research trends.	To further narrow the gap between AI and CEM, six key directions of future researches, such as smart robotics, cloud virtual and augmented reality (cloud VR/AR), Artificial Intelligence of Things (AIoT), digital twins, 4D printing, and blockchains, are highlighted to constantly facilitate the automation and intelligence in CEM.	Artificial intelligence, Construction engineering and management, Critical review	Architectural design, Augmented reality, Computational electromagnetics, Computer vision, Intelligent robots, Data mining, Expert systems, Knowledge representation, Life cycle, Natural language processing systems, Building Information Model - BIM, Construction engineering, Digital transformation, Hot research topics, Knowledge representation and reasoning, NAtural language processing, Qualitative analysis, Virtual and augmented reality, Digital twin	Management	AI
Wang H.-W.	2020	Automation in Construction	9	10.1016/j.autcon.2019.102958	Work package-based information modeling for resource-constrained scheduling of construction projects	As an essential problem in construction management, the resource-constrained project scheduling problem (RCPSP) has been studied for decades. however, an integrated information model that fully supports the RCPSP solving process is still lacking. Though building information modeling (BIM) was proposed to meet the data requirements in the building life cycle, some scheduling and resource information are not considered in information transfers between the information model and the RCPSP mathematical model. This paper presents an integrated approach that enables fluent data flow from the information model to the RCPSP model for construction scheduling. Within this approach, a work package-based information model is proposed to capture all the required data of the RCPSP. Then, a semiautomatic method that integrates multisource data is introduced to form the proposed information model, and an adaptive data transmission method is used to support a designed multimode resource-constrained project scheduling problem (MRCPSP) model. The models and approaches are validated using the data of an actual project, demonstrating the feasibility and efficiency. This study contributes a novel integrated approach to formalizing a construction information model using a semiautomatic data integration approach, covering the information requirement and enables fluent data flow in the RCPSP solving process. Meanwhile, the work package-based information model is a successful attempt to introduce previously-gained knowledge into automatic schedule generation processes. Future work, such as extending the information model, creating new methods for RCPSP model generation, and data analytics, can bring new opportunities to apply more complex and intelligent methods in project scheduling and construction management. © 2019 Elsevier B.V.	This paper presents an integrated approach that enables fluent data flow from the information model to the RCPSP model for construction scheduling. Within this approach, a work package-based information model is proposed to capture all the required data of the RCPSP.	Meanwhile, the work package-based information model is a successful attempt to introduce previously-gained knowledge into automatic schedule generation processes. Future work, such as extending the information model, creating new methods for RCPSP model generation, and data analytics, can bring new opportunities to apply more complex and intelligent methods in project scheduling and construction management. © 2019 Elsevier B.V.	Constraint programming Data integration, Information modeling, Optimization, Resource-constrained scheduling, Data Analytics, Work package	Architectural design, Constrained optimization, Data flow analysis, Data integration, Data transfer, Information theory, Integrated control, Life cycle, Optimization, Scheduling, Adaptive data transmission, Building Information Model - BIM, Constraint programming, Information Modeling, Multi-mode resource-constrained project scheduling problem, Resource constrained scheduling, Resource-constrained project scheduling problem	Design	Analytics
Ramprasad B.	2018	IEEE World Forum on Internet of Things, WF-IoT 2018 - Proceedings	9	10.1109/WF-IoT.2018.8355121	Leveraging existing sensor networks as IoT devices for smart buildings	As the Internet-of-Things (IoT) grows and data analytics mature, their application to new buildings is proved a significant opportunity for improved building performance at reduced energy costs. In existing buildings, however, the cost to replace existing Building Management Systems (BMS) with IoT-compatible devices poses a barrier to adoption. Additionally, the limited data storage on these existing systems further precludes data analytics for optimization - This research responds to this need by presenting a novel approach to pre-process and stream the BMS data to a cloud-based database on a private network. Afterwards, in the centralized data warehouse, larger scale and more complex analytics can be performed. This paper presents the development of both the new database architecture and supporting infrastructure to support the streaming of BMS, as well as the pre-processing to optimize big data analytics and visualization. A proof-of-concept visualization for a 14,000m2 student learning center is presented to demonstrate the application of this architecture. © 2018 IEEE.	This paper presents the development of both the new database architecture and supporting infrastructure to support the streaming of BMS, as well as the pre-processing to optimize big data analytics and visualization.	This research responds to this need by presenting a novel approach to pre-process and stream the BMS data to a cloud-based database on a private network.Afterwards, in the centralized data warehouse, larger scale and more complex analytics can be performed.	big data, building information model, internet of things, sensor networks, smart buildings	Big data, Data visualization, Intelligent buildings, Data warehouses, Digital storage, Network architecture, Sensor networks, Visualization, Big Data Analytics, Building Information Model - BIM, Building management system, Building performance, Database architecture, Existing systems, Internet of thing (IOT), Private networks, Internet of things	Analysis	AI
Lin J.J.	2018	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	9	10.1007/978-3-319-91635-4_21	Visual data and predictive analytics for proactive project controls on construction sites	This paper presents the theoretical foundation for a project controls system that improves understanding of how construction performance can be captured, communicated, and analyzed in form of a visual production system, predicts and effectively communicates the reliability of the weekly work plan and look-ahead schedules, supports root-cause assessment on plan failure at both project and task-levels facilitates information flows and decentralizes decision-making. Our model-driven system builds upon novel visual data analytics to map the current state of production in 4D (3D+time), compare to 4D BIM, and expose waste at both project and task-levels. Using predictive analytics and based on actual progress and productivity data, reliability in the future state of production is forecasted to highlight potential issues in a location-driven scheme and support collaborative decision making that eliminates root causes of waste. To evaluate the performance of our system, several case studies are conducted on real-world commercial building projects. It is shown that the developed system provides visual interfaces between people and information on and offsite, enables effective pull flows, decentralizes work tracking, facilitates in-process quality control and hand-overs among contractors, and most importantly transforms retroactive and task-driven workflows in contractor coordination meetings to proactive location-driven practices. © Springer International Publishing AG, part of Springer Nature 2018.	This paper presents the theoretical foundation for a project controls system that improves understanding of how construction performance can be captured, communicated, and analyzed in form of a visual production system, predicts and effectively communicates the reliability of the weekly work plan and look-ahead schedules, supports root-cause assessment on plan failure at both project and task-levels facilitates information flows and decentralizes decision-making.	It is shown that the developed system provides visual interfaces between people and information on and offsite, enables effective pull flows, decentralizes work tracking, facilitates in-process quality control and hand-overs among contractors, and most importantly transforms retroactive and task-driven workflows in contractor coordination meetings to proactive location-driven practices. © Springer International Publishing AG, part of Springer Nature 2018.	Lean construction, Predictive data analytics, Visual production management	Architectural design, Behavioral research, Contractors, Decision making, Project management, Intelligent computing, Office buildings, Quality control, Collaborative decision making, Commercial building, Construction performance, Construction sites, Data analytics, Lean construction, Production management, Theoretical foundations, Predictive analytics	Management	Analytics
Zhou Y.-W.	2020	Archives of Computational Methods in Engineering	8	10.1007/s11831-019-09356-6	A Review on 3D Spatial Data Analytics for Building Information Models	Except for various properties, accurate and intuitive 3D representations of building elements and spaces are embedded in Building Information Models (BIMs). Thus, better understanding of spatial features of building elements and spaces is possible, which brings new opportunity in code compliance checking, indoor navigation, visualization, etc. With large amount of fine-grained 3D spatial data collected quickly and continuously, there is an urgent need for new methods to overcome problems like improper spatial expression, insufficient mining and utilization of information that exist in traditional methods. This research reviews state-of-the-art of related research and provides a summary of achievements and challenges in this area. Then, a framework consists of management, analysis, and application of 3D spatial data of BIM and a detailed discussion of each part are proposed, which would give the readers an overview of relevant methods, technologies, and tools. Moreover, potential research directions and open issues for future work are also discussed. The paper enables researchers to get a comprehensive understanding of 3D spatial data analytics of BIM as well as suggestions for future work, and thus makes a solid contribution in this area. © 2019, CIMNE, Barcelona, Spain.	This research reviews state-of-the-art of related research and provides a summary of achievements and challenges in this area. Then, a framework consists of management, analysis, and application of 3D spatial data of BIM and a detailed discussion of each part are proposed, which would give the readers an overview of relevant methods, technologies, and tools.	The paper enables researchers to get a comprehensive understanding of 3D spatial data analytics of BIM as well as suggestions for future work, and thus makes a solid contribution in this area. © 2019, CIMNE, Barcelona, Spain.	Building information model, Data retrieval, Interoperability, Model checking, Spatial analysis, Spatial database, Data Analytics, Spatio-semantic analysis	Building components, Compliance control, Data visualization, Information theory, Interoperability, Model checking, Semantics, Three dimensional computer graphics, Building Information Model - BIM, Data retrieval, Semantic analysis, Spatial analysis, Spatial database, Architectural design	Management	BIM
Zhang Y.-Y.	2020	International Journal of Distributed Sensor Networks	7	10.1177/1550147720908170	Building information modeling-based cyber-physical platform for building performance monitoring	Building performance management requires massive data input, however, the relevant data are separated and heterogeneous thus, it prevents a comprehensive building performance management. Building information modeling brings a new way to capture rich information of a building, and has great potential in data interoperability for building performance management. This article presents a scalable building information modeling-based cyber-physical platform for building performance monitoring to integrate heterogeneous data from different buildings. A smart sensor network based on Arduino and standard protocol is installed for data sensing and collection. A building information modeling-based sensing information model integrating heterogeneous data in a unified structure is proposed, and a scalable NoSQL database is established to store data in a cloud environment. A series of RESTful web services is developed to share data for building performance management applications. The proposed platform is developed taking the advantage of horizontal scalability of NoSQL database, and the data schema and services are generated automatically based on the unified data model. The platform has collected data from 77 buildings in China, and the results of a case study show the platform brings a new paradigm in collecting, storing, integrating, and sharing of sensor data and building information for building performance monitoring and analytics. © The Author(s) 2020.	This article presents a scalable building information modeling-based cyber-physical platform for building performance monitoring to integrate heterogeneous data from different buildings. A smart sensor network based on Arduino and standard protocol is installed for data sensing and collection. A building information modeling–based sensing information model integrating heterogeneous data in a unified structure is proposed, and a scalable NoSQL database is established to store data in a cloud environment.	The platform has collected data from 77 buildings in China, and the results of a case study show the platform brings a new paradigm in collecting, storing, integrating, and sharing of sensor data and building information for building performance monitoring and analytics. © The Author(s) 2020.	Building information modeling, building performance, cyber-physical platform, interoperability, NoSQL database, sensor network, Cyber Physical System, system automation, web service	Architectural design, Data integration, Graph Databases, Information theory, Interoperability, Sensor networks, Web services, Websites, Building information Model - BIM, Building performance, Cyber physicals, Nosql database, System automa-tion, Data Sharing	Design	BIM

Jin R.	2019	Journal of Construction Engineering and Management	7	10.1061/(ASCE)CO.1943-7862.0001682	Scientometric review of articles published in ASCE's journal of construction engineering and management from 2000 to 2018	This study aims to address research questions related to the evolution of academic research in the field of construction engineering and management (CEM): (1) what are the mainstream research topics since 2000? (2) what are the emerging topics or techniques in CEM within the recent decades? and (3) what are potential CEM research areas in the near future? A scientometric analysis was conducted to review articles published in Journal of Construction Engineering and Management since 2000, follow by a qualitative discussion. This study revealed that project performance indicator-related topics (e.g., cost, scheduling, safety, productivity, and risk management) have been the ongoing mainstream issues over the last decades. Labor and personnel issues gained even more research attention in the last 10 years. Information and communication technologies (e.g., building information modeling (BIM)) applied in CEM has been gaining the momentum since 2008. A variety of quantitative methods have gained popularity in the CEM discipline, such as algorithms, statistics, fuzzy sets, and neural networks. The follow up qualitative analysis led to the contributions of this review-based study in terms that (1) it provided an overview of the research topics in CEM since 2000 through a text-mining approach, and (2) it offered insights into emerging and near-future research areas, including BIM and data analytics applied in various construction issues (e.g., safety), as well as integrations of research themes (e.g., risk assessment in newly emerging project delivery methods). © 2019 American Society of Civil Engineers.	This study aims to address research questions related to the evolution of academic research in the field of construction engineering and management (CEM): (1) what are the mainstream research topics since 2000? (2) what are the emerging topics or techniques in CEM within the recent decades? and (3) what are potential CEM research areas in the near future?	The follow-up qualitative analysis led to the contributions of this review-based study in terms that (1) it provided an overview of the research topics in CEM since 2000 through a text-mining approach, and (2) it offered insights into emerging and near-future research areas, including BIM and data analytics applied in various construction issues (e.g., safety), as well as integrations of research themes (e.g., risk assessment in newly emerging project delivery methods).	Construction engineering and management Literature review, Scientometric analysis, Text mining	Architectural design, Computational electromagnetics, Risk assessment, Data Analytics, Fuzzy neural networks, Risk management, Safety engineering, Scheduling, Building Information Model - BIM, Construction engineering, Information and Communication Technologies, Literature reviews, Project delivery method, Qualitative analysis, Scientometric analysis, Text mining, Data mining	Management	BIM
Bao Y.	2019	Tumu Gongcheng Xuebao/China Civil Engineering Journal	7		Artificial intelligence for civil engineering	Artificial Intelligence (AI) brings new opportunities for the development of civil engineering disciplines. AI technology deeply integrates the whole life cycle of civil infrastructure planning, design, construction and maintenance, and profoundly transforms the development of civil engineering. The deep learning, machine learning and reinforcement learning algorithms, computer vision, UAV, 3D printing, BIM, virtual reality and augmented reality techniques are applied to civil engineering, which will form urban and regional planning with unmanned, fully automatic, intelligent and real experience, as well as new technologies for civil engineering design, construction, maintenance, and disaster management. This article expounds the related research and application of AI in the field of civil engineering from the aspects of AI-based urban intelligent planning, intelligent structural design, intelligent construction, intelligent maintenance, and intelligent disaster prevention. © 2019, Editorial Office of China Civil Engineering Journal. All right reserved.	This article expounds the related research and application of AI in the field of civil engineering from the aspects of AI-based urban intelligent planning, intelligent structural design, intelligent construction, intelligent maintenance, and intelligent disaster prevention.	Artificial Intelligence (AI) brings new opportunities for the development of civil engineering disciplines. AI technology deeply integrates the whole life cycle of civil infrastructure planning, design, construction and maintenance, and profoundly transforms the development of civil engineering.	3D printing, Artificial Intelligence, BIM, Computer vision, Deep learning, UAV	3D printers, Augmented reality, Architectural design, Artificial Intelligence, Computer vision, Deep learning, Disaster prevention, Disasters, Intelligent well technology, Learning algorithms, Life cycle, Machine learning, Maintenance, Regional planning, Reinforcement learning, Structural design, Unmanned aerial vehicles (UAV), Virtual reality, 3-D printing	Design	AI
Stojanovic V.	2018	Proceedings - Web3D 2018: 23rd International ACM Conference on 3D Web Technology	7	10.1145/3208806.3208810	A service-Oriented approach for classifying 3D points clouds by example of office furniture classification	The rapid digitalization of the Facility Management (FM) sector has increased the demand for mobile, interactive analytics approaches concerning the operational state of a building. These approaches provide the key to increasing stakeholder engagement associated with Operation and Maintenance (O&M) procedures of living and working areas, buildings, and other built environment spaces. We present a generic and fast approach to process and analyze given 3D point clouds of typical indoor office spaces to create corresponding up-to-date approximations of classified segments and object-based 3D models that can be used to analyze, record and highlight changes of spatial configurations. The approach is based on machine-learning methods used to classify the scanned 3D point cloud data using 2D images. This approach can be used to primarily track changes of objects over time for comparison, allowing for routine classification, and presentation of results used for decision making. We specifically focus on classification, segmentation, and reconstruction of multiple different object types in a 3D point-cloud scene. We present our current research and describe the implementation of these technologies as a web-based application using a services-oriented methodology. © 2018 Association for Computing Machinery.	We present a generic and fast approach to process and analyze given 3D point clouds of typical indoor office spaces to create corresponding up-to-date approximations of classified segments and object-based 3D models that can be used to analyze, record and highlight changes of spatial configurations. The approach is based on machine-learning methods used to classify the scanned 3D point cloud data using 2D images	This approach can be used to primarily track changes of objects over time for comparison, allowing for routine classification, and presentation of results used for decision making	3D point clouds, BIM, Indoor models, Machine-learning, Service-oriented	Architectural design, Artificial Intelligence, Information services, Computer integrated manufacturing, Decision making, Learning systems, Office buildings, 3D point cloud, Facility management, Operation and maintenance, Service Oriented, Service-oriented approaches, Spatial configuration, Stakeholder engagement, Web-based applications, Web services	Management	AI
Arthur S.	2017	IFIP Advances in Information and Communication Technology	7	10.1007/978-3-319-65151-4_6	A collaborative unified computing platform for building information modelling (BIM)	The current dominant computing mode in the AEC (Architecture, Engineering and Construction) domain is standalone based, causing fragmentation and fundamental interoperability problems. This makes the collaboration required to deal with the interconnected and complex tasks associated with a sustainable and resilient built environment extremely difficult. This article aims to discuss how the latest computing technologies can be leveraged for the AEC domain and Building Information Modelling (BIM) in particular. These technologies include Cloud Computing, the Internet of Things and Big Data Analytics. The data rich BIM domain will be analysed to identify relevant characteristics, opportunities and the likely challenges. A clear case will be established detailing why BIM needs these technologies and how they can be brought together to bring about a paradigm shift in the industry. Having identified the potential application of new technologies, a future platform will be proposed. It will carry out large scale, real-time processing of data from all stakeholders. The platform will facilitate the collaborative interpretation, manipulation and analysis of data for the whole lifecycle of building projects. It will be flexible, intelligent and able to autonomously execute analysis and choose the relevant tools. This will form a base for a step-change for computing tools in the AEC domain. © IFIP International Federation for Information Processing 2017.	This article aims to discuss how the latest computing technologies can be leveraged for the AEC domain and Building Information Modelling (BIM) in particular. These technologies include Cloud Computing, the Internet of Things and Big Data Analytics. The data rich BIM domain will be analysed to identify relevant characteristics, opportunities and the likely challenges. A clear case will be established detailing why BIM needs these technologies and how they can be brought together to bring about a paradigm shift in the industry.	Having identified the potential application of new technologies, a future platform will be proposed. It will carry out large scale, real-time processing of data from all stakeholders. The platform will facilitate the collaborative interpretation, manipulation and analysis of data for the whole lifecycle of building projects. It will be flexible, intelligent and able to autonomously execute analysis and choose the relevant tools. This will form a base for a step-change for computing tools in the AEC domain. © IFIP International Federation for Information Processing 2017.	Big data, BIM, Building information modelling, Cloud computing, Collaboration, IoT	Big data, Information theory, Cloud computing, Data handling, Internet of things, Virtual corporation, Architecture , engineering and constructions, Building Information Modelling, Built environment, Collaboration, Computing platform, Computing technology, Realtime processing, Whole life cycles, Architectural design	Design	BIM
Nekhgar S.	2013	Lecture Notes in Business Information Processing	6	10.1007/978-3-642-41641-5_9	From business intelligence insights to actions: A methodology for closing the sense-and-respond loop in the adaptive enterprise	Business Intelligence (BI) and analytics play a critical role in modern businesses by assisting them to gain insights about internal operations and the external environment and to make timely data-driven decisions. Actions resulting from these insights often require changes to various parts of the enterprise. A significant challenge in these contexts is to systematically connect and coordinate the BI-driven insights with consequent enterprise decisions and actions. This paper proposes a methodology for closing the gap between what an enterprise senses from BI-driven insights and its response actions and changes. This methodology adopts and synthesizes existing modeling frameworks, mainly i* and the Business Intelligence Model (BIM), to provide a coherent step-by-step way of connecting the sensed signals of the enterprise to subsequent responses, and hence to make BI and analytics more actionable and understandable. Applicability of the proposed methodology is illustrated in a case scenario. © IFIP International Federation for Information Processing 2013.	This paper proposes a methodology for closing the gap between what an enterprise senses from BI-driven insights and its response actions and changes.	This methodology adopts and synthesizes existing modeling frameworks, mainly i* and the Business Intelligence Model (BIM), to provide a coherent step-by-step way of connecting the sensed signals of the enterprise to subsequent responses, and hence to make BI and analytics more actionable and understandable. Applicability of the proposed methodology is illustrated in a case scenario. © IFIP International Federation for Information Processing 2013.	Adaptive enterprise, Business Intelligence, Data analytics, Modeling framework, Sense-and-respond	Competitive intelligence, Data Analytics, Data driven decision, Data processing, Adaptive enterprise, External environments, Gain insight, Internal operations, Model framework, Sense-and-respond, Data analytics, nocv1, Information analysis	Analysis	Analytics
Rouhestani S.	2020	Automation in Construction	5	10.1016/j.autcon.2019.103069	IFC-based process mining for design authoring	Building Information Modelling (BIM) is defined as the process of creation and management of digital replica for building products in a collaborative design set-up. On this basis, BIM as a digital collaboration platform in AECO (Architecture, Engineering, Construction, and Operation) industry, can be upgraded to assist monitoring, control and improvement of the business processes related to planning, design, construction and operation of building facilities. The main problem in this regard, is the wastage of data related to activities completed by different actors during the project, and subsequently, the lack of analytics to discover latent patterns in collaboration and execution of such processes. The present study aims to enable BIM to capture digital footprints of project actors and create event logs for design authoring phase of building projects. This is done using files in IFC (Industry Foundation Classes) format, archived during the design process. We have developed algorithms to create event logs from such archives, and analysed the event logs using process mining (i.e. process discovery, conformance checking and bottleneck analysis), to identify measures derived from as-happened processes. BIM managers can implement such measures in monitoring, controlling and re-engineering work processes related to design authoring. Two case studies were completed to validate and verify the products and findings of the research. Our results show that process models discovered/fine-tuned at various resolutions and from different perspectives (including 'actor-centric' and 'phase-centric' views) can provide a realistic view of the BIM project execution. This includes understanding the structure of collaboration and hand-over of work evaluation of compliance with the BIM execution plan and detection of bottlenecks and re-works. While the scope of the study has been limited to design authoring processes, this mindset can be extended to other BIM uses, and other phases (such as construction and operation) of building projects. Given the growing efforts on upgrading BIM to capture and formalize the lifecycle data on the products, processes and actors, this study can strongly support BIM managers with documentation and evaluation of the business processes and workflows in their project teams. © 2019	The present study aims to enable BIM to capture digital footprints of project actors and create event logs for design authoring phase of building projects. This is done using files in IFC (Industry Foundation Classes) format, archived during the design process.	While the scope of the study has been limited to design authoring processes, this mindset can be extended to other BIM uses, and other phases (such as construction and operation) of building projects. Given the growing efforts on upgrading BIM to capture and formalize the lifecycle data on the products, processes and actors, this study can strongly support BIM managers with documentation and evaluation of the business processes and workflows in their project teams. © 2019	BIM Execution Planning BIM management, Building Information Modeling, Process mining	Construction, Business processes management, Data mining, Data mining, Human resource management, Information theory, Life cycle, Managers, Product design, Structural design, Building Information Model - BIM, Building Information Modelling, Business Process, Collaborative design, Digital collaborations, Execution planning, Industry Foundation Classes - IFC, Process mining	Design	BIM
Mansouri S.	2020	Journal of Construction Engineering and Management	5	10.1061/(ASCE)CO.1943-7862.0001759	Analysis of the Synergistic Effect of Data Analytics and Technology Trends in the AEC/FM Industry	Technological advancements focusing on effective and efficient information modeling, visualization, resource tracking, and collaboration have gained substantial traction in the architectural, engineering, construction, and facility management (AEC/FM) industry in the last 10 years. The use of advanced technologies has resulted in safer jobsites hosting more productive project teams building more sustainable and resilient facilities and infrastructure. Recently, the innovative use of data and analytical approaches has had a major positive effect on a variety of businesses by incorporating data-driven applications and approaches. However, the AEC/FM industry is still lagging behind many other industries in leveraging the true power of data. Data analytics concepts and tools integrated with emerging construction trends such as building information modeling (BIM) have a high potential to revolutionize industry practices. This paper consolidates the record of current efforts in the AEC/FM body of knowledge (BOK) and body of practice (BOP) that incorporate the use of Data Analytics with common Technology Trends in various Application Areas. Identifying common subsections of each category, a three dimensional evidenced taxonomy was developed that maps (1) Data Analytics concepts such as cloud computing and machine learning onto, (2) AEC/FM emerging trends such as BIM and automation, and (3) existing and potential AEC/FM applications such as safety and progress monitoring. To further expand the validity of the results and explore opportunities and potential, a survey with the same categorization was developed and distributed among industry experts. Comparing the results of the exploration of the BOK and the survey illustrated the popularity of BIM among industry practitioners and in academic research. Also, process efficiency and productivity improvement were the two Application Areas that demonstrated the most potential to benefit from the integration of Data Analytics and Technology Trends. Analysis of the survey results indicated that, with a 95% confidence level, there is no statistically significant difference among the Technology Trends or Application Areas, as identified in the literature, that can benefit from Data Analytics. The results presented in this study demonstrate evidence of the revolutionizing power of Data Analytics in the AEC/FM industry. © 2019 American Society of Civil Engineers.	This paper consolidates the record of current efforts in the AEC/FM body of knowledge (BOK) and body of practice (BOP) that incorporate the use of Data Analytics with common Technology Trends in various Application Areas.	Also, process efficiency and productivity improvement were the two Application Areas that demonstrated the most potential to benefit from the integration of Data Analytics and Technology Trends. Analysis of the survey results indicated that, with a 95% confidence level, there is no statistically significant difference among the Technology Trends or Application Areas, as identified in the literature, that can benefit from Data Analytics. The results presented in this study demonstrate evidence of the revolutionizing power of Data Analytics in the AEC/FM industry. © 2019 American Society of Civil Engineers.	Architectural design, Information management, Information theory, Office buildings, Productivity, Surveys, Building Information Model - BIM, Advanced technology, Analytical approach, Data-driven applications, Information Modeling, Productivity improvements, Statistically significant difference, Technological advancement, Data Analytics		Analysis	BIM
Golovina O.	2019	Automation in Construction	5	10.1016/j.autcon.2018.11.014	Algorithm for quantitative analysis of close call events and personalized feedback in construction safety	In many of the developed countries about 15–25% of all fatal construction workplace accidents relate to a too close proximity of pedestrian workers to construction equipment or hazardous materials. Extracting knowledge from data on near hits (aka. close calls) might warrant better understanding on the root causes that lead to such incidents and eliminate them early in the risks mitigation process. While a close call is a subtle event where workers are in close proximity to a hazard, its frequency depends–among other factors–on poor site layout, a worker's willingness to take risks, limited safety education, and pure coincidence. For these reasons, pioneering organizations have recognized the potential of gathering and analyzing leading indicator data on close calls. However, mostly manual approaches are infrequently performed, subjective due to situational assessment, imprecise in level of detail, and importantly, reactive or inconsistent in effective or timely follow-ups by management. While existing predictive analytics research targets change at strategic levels in the hierarchy of organizations, personalized feedback to strengthen an individual worker's hazard recognition and avoidance skill set is yet missing. This study tackles the bottom of Heinrich's safety pyramid by providing an in-depth quantitative analysis of close calls. Modern positioning technology records trajectory data, whereas computational algorithms automatically generate previously unavailable details to close call events. The derived information is embedded in simplified geometric information models that users on a construction site can retrieve, easily understand, and adapt in existing preventative hazard recognition and control processes. Results from scientific and field experiments demonstrate that the developed system works successfully under the constraints of currently available positioning technology. © 2018 Elsevier B.V.	This study tackles the bottom of Heinrich's safety pyramid by providing an in-depth quantitative analysis of close calls. Modern positioning technology records trajectory data, whereas computational algorithms automatically generate previously unavailable details to close call events. The derived information is embedded in simplified geometric information models that users on a construction site can retrieve, easily understand, and adapt in existing preventative hazard recognition and control processes.	Results from scientific and field experiments demonstrate that the developed system works successfully under the constraints of currently available positioning technology. © 2018 Elsevier B.V.	Accident investigation, Building information modeling, Close call, Construction safety, Data recording, visualization, data mining, Education and training, Near miss, Hazard identification, Location tracking, Predictive analytics	Accidents, Construction equipment, Data visualization, Feedback, Hazardous materials, Hazards, Information theory, Predictive analytics, Tracking (position), Accident investigation, Building Information Model - BIM, Close call, Construction safety, Education and training, Hazard identification	Analysis	Analytics

Saeki R.	2019	Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation - Selected Papers from the ASCE International Conference on Computing in Civil Engineering 2019	5	10.1061/9780784482421.045	Automating Design Review with Artificial Intelligence and BIM: State of the Art and Research Framework	Today's model checking applications are capable of checking building models for conformance to code clauses which restrict explicit dimension values, but very little more than that. Comples, implicit code clauses are still beyond the scope of such applications. Much research and development is needed for semantic enrichment (to pre-process models for checking) and for automating checking of complex conditions. A review of the state-of-the-art reveals that research and development has been limited to the application of symbolic AI methods, such as rule inferencing. Based on this review and on a set of early experiments designed to test basic feasibility, the authors propose a framework for research and development that specifically extends current thinking to include machine learning methods for both semantic enrichment and model review. Machine learning is shown to be applicable in situations where expression of the constraints in the form of explicit rules is impractical. © 2019 American Society of Civil Engineers.	Based on this review and on a set of early experiments designed to test basic feasibility, the authors propose a framework for research and development that specifically extends current thinking to include machine learning methods for both semantic enrichment and model review.	Machine learning is shown to be applicable in situations where expression of the constraints in the form of explicit rules is impractical. © 2019 American Society of Civil Engineers.	Architectural design, Information theory, Machine learning, Semantics, Visualization, Building model, Model reviews, Complex condition, Machine learning methods, Research and development, Research frameworks, Semantic enrichment, State of the art, Model checking		Design	BIM
Marroquin R.	2018	Semantic Web	5	10.3233/SW-180298	Ontology for a Panoptes building: Exploiting contextual information and a smart camera network	The contextual information in the built environment is highly heterogeneous, it goes from static information (e.g., information about the building structure) to dynamic information (e.g., user's space-time information, sensors detections and events that occurred). This paper proposes to semantically fuse the building's contextual information with extracted data from a smart camera network by using ontologies and semantic web technologies. The developed ontology allows interoperability between the different contextual data and enables, without human interaction, real-time event detections and system reconfiguration to be performed. The use of semantic knowledge in multi-camera monitoring systems guarantees the protection of the user's privacy by not sending nor saving any image, just extracting the knowledge from them. This paper presents a new approach to develop an all-seeing smart building, where the global system is the first step to attempt to provide Artificial Intelligence (AI) to a building. © 2018 - IOS Press and the authors. All rights reserved.	This paper proposes to semantically fuse the building's contextual information with extracted data from a smart camera network by using ontologies and semantic web technologies.	The use of semantic knowledge in multi-camera monitoring systems guarantees the protection of the user's privacy by not sending nor saving any image, just extracting the knowledge from them. This paper presents a new approach to develop an all-seeing smart building, where the global system is the first step to attempt to provide Artificial Intelligence (AI) to a building. © 2018 - IOS Press and the authors. All rights reserved.	BIM, building AI, context-aware system, IFC, semantic gap, semantic interoperability smart camera network		Analysis	BIM
Mansouri S.	2018	Construction Research Congress 2018: Infrastructure and Facility Management - Selected Papers from the Construction Research Congress 2018	5	10.1061/9780784481295.010	The Status Quo and Future Potentials of Data Analytics in AEC/FM: A Quantitative Analysis of Academic Research and Industry Outlook	In the present era of data analytics, industries leverage the power embedded in the abundant data generated rapidly to improve procedures and facilitate decision making. The architectural, engineering, construction, and facility management (AEC/FM) industry as well, begins to realize the benefits of data-driven approaches. However, AEC/FM is still behind many other industries in leveraging the advantages of data. During the last decade, researchers have focused their attention to emerging construction trends such as building information modeling (BIM). Integrated with data analytics, such trends have high potential to continue the technology evolution of the industry. This paper consolidates the records of current relevant efforts in AEC/FM academic research and evaluates the conclusions from this literature exploration through an industry survey. Following a comprehensive literature review, a three dimensional evidenced taxonomy was developed by categorizing the primary concepts into related segments that maps: (1) data analytics concepts such as cloud computing and machine learning, onto (2) AEC/FM emerging trends such as BIM and automation, and (3) existing and potential AEC/FM applications such as safety and progress monitoring. The same categorization was used to conduct the survey. Statistical analysis of the survey results indicates a general agreement between the literature-based identified technology trends and application areas that can benefit from data. BIM exhibited the most promising Technology Trend when integrated with data analytics in both literature and industry surveys. As for the application areas, process efficiency and productivity improvement ranked the highest in the literature and industry survey, respectively. This study contributes to the body of knowledge and practice by creating an evidenced account of the existing frameworks that benefit from data analytics and future potentials from both the academic and industry standpoints. © 2018 American Society of Civil Engineers (ASCE). All rights reserved.	This paper consolidates the records of current relevant efforts in AEC/FM academic research and evaluates the conclusions from this literature exploration through an industry survey. Following a comprehensive literature review, a three dimensional evidenced taxonomy was developed by categorizing the primary concepts into related segments that maps: (1) data analytics concepts such as cloud computing and machine learning, onto (2) AEC/FM emerging trends such as BIM and automation, and (3) existing and potential AEC/FM applications such as safety and progress monitoring. The same categorization was used to conduct the survey.	This study contributes to the body of knowledge and practice by creating an evidenced account of the existing frameworks that benefit from data analytics and future potentials from both the academic and industry standpoints. © 2018 American Society of Civil Engineers (ASCE). All rights reserved	Decision making, Industrial research, Learning systems, Office buildings, Productivity, Surveys, Data-driven approach, Building Information Model - BIM, Construction trends, Facility management, Literature reviews, Process efficiency, Productivity improvements, Technology evolution, Architectural design		Analysis	BIM
Hamid Z.	2011	ICCAR 2011 - 2011 IEEE Conference on Computer Applications and Industrial Electronics	5	10.1109/ICCAIE.2011.6162112	Comparative studies between various power tracing techniques for reactive power allocation	The inability of traditional methods in providing fair and non-discriminatory transmission service pricing has attracted many researchers to streamline the existing methods, or invent some methods that can improve the weakness. Transaction based allocation like MW mile, contract path, and postage stamp allocation are the examples of traditional technique applied by many transmission service providers (TRANSCO) for allocating transmission usage cost among consumers, the generation (GENCO) and distribution (DISCO) companies. Unfortunately, such methods ignore the physical power system constraints such as flow, sink and source constraints that should be taken into account when performing the cost allocation. Thus, a method that can accurately determine the cost of utilizing transmission service while satisfying those constraints has been developed, known as power tracing. This paper tries to conduct an investigation on various power tracing techniques that are based on Artificial Intelligence (AI) based optimization, proportional sharing principle (PSP), and circuit theory. Validation has been performed on IEEE 14 bus reliability test system (RTS) and it is revealed that different power tracing techniques provide different reactive power allocation on consumers. © 2011 IEEE.	This paper tries to conduct an investigation on various power tracing techniques that are based on Artificial Intelligence (AI) based optimization, proportional sharing principle (PSP), and circuit theory.	Validation has been performed on IEEE 14 bus reliability test system (RTS) and it is revealed that different power tracing techniques provide different reactive power allocation on consumers. © 2011 IEEE	IEEE 14 bus reliability test system (RTS), IEEE 14 bus reliability test system (RTS), Reactive power allocation, TLDF		Analysis	BIM
Haymaker J.R.	2011	AAAI Spring Symposium - Technical Report	5		Opportunities for AI to improve sustainable building design processes	Sustainable building design is a complex social and technical process in which a broad range of stakeholders must construct and clearly communicate high quality design spaces. This paper summarizes recent assessments of current practice that illustrate how far industry today is from achieving this quality and clarity. Efforts to develop a platform of tools to address these limitations are discussed. PIP helps people communicate, share, and understand collaborative design processes, MACDADI helps project teams identify and manage rationale and consensus on decisions Design Scenarios helps them generate requirements-driven alternative spaces, BIM, model-based analysis, and PIDO which helps to systematically assess these alternatives for their energy, daylight, structural, and cost impacts and iRooms and the web, which help to communicate all of this information to engage designers, stakeholders, and decision makers in fast, multidisciplinary design and analysis processes. This new platform considerably improves the quality and clarity of AEC design spaces. However additional work would enable significant additional improvement. The paper concludes with a proposal for how AI might further improve the performance of this platform.	This paper summarizes recent assessments of current practice that illustrate how far industry today is from achieving this quality and clarity. Efforts to develop a platform of tools to address these limitations are discussed.	This new platform considerably improves the quality and clarity of AEC design spaces. However additional work would enable significant additional improvement. The paper concludes with a proposal for how AI might further improve the performance of this platform.	Collaborative design Cost impact, Decision makers, Model-based analysis, Design spaces, High quality design, Multi-disciplinary designs, Project team, Sustainable building design, Technical process, Architectural design, Artificial intelligence, Intelligent buildings, Sustainable development, User interfaces, Structural design		Design	AI
Wang M.	2020	Buildings	4	10.3390/buildings10110204	A systematic review of digital technology adoption in off-site construction: Current status and future direction towards industry 4.0	Off-site construction (OSC) is known as an efficient construction method that could save time and cost, reduce waste of resources, and improve the overall productivity of projects. Coupled with digital technologies associated with the industry 4.0 concept, OSC can offer a higher rate of productivity and safety. While there is a rich literature focusing on both OSC and Industry 4.0, the implementation of associated digital technologies in the OSC context has not been fully evaluated. This paper intends to evaluate the current literature of digital technology applications in OSC. Scientometric analyses and a systematic review were carried out evaluating fifteen typical digital technologies adopted by OSC projects, including building information modelling (BIM), radio frequency identification devices (RFID), global positioning systems (GPS), the Internet of Things (IoT), geographic information systems (GIS), sensors, augmented reality (AR), virtual reality (VR), photogrammetry, laser scanning, artificial intelligence (AI), 3D printing, robotics, big data, and blockchain. This review formulates a clear picture of the current practice of these digital technologies and summarizes the main area of application and limitations of each technology when utilized in OSC. The review also points out their potential and how they can be better adopted to improve OSC practice in the future. © 2020 by the authors. Licensee MDPI, Basel, Switzerland.	This paper intends to evaluate the current literature of digital technology applications in OSC. Scientometric analyses and a systematic review were carried out evaluating fifteen typical digital technologies adopted by OSC projects, including building information modelling (BIM), radio frequency identification devices (RFID), global positioning systems (GPS), the Internet of Things (IoT), geographic information systems (GIS), sensors, augmented reality (AR), virtual reality (VR), photogrammetry, laser scanning, artificial intelligence (AI), 3D printing, robotics, big data, and blockchain.	This review formulates a clear picture of the current practice of these digital technologies and summarizes the main area of application and limitations of each technology when utilized in OSC. The review also points out their potential and how they can be better adopted to improve OSC practice in the future. © 2020 by the authors. Licensee MDPI, Basel, Switzerland.	BIM, Modular construction, Prefabricated construction, Prefabrication, Technology adoption		Analysis	BIM
Helemi E.	2020	Sustainability (Switzerland)	4	10.3390/su12093893	An institutional approach to digitalization in sustainability-oriented infrastructure projects: The limits of the building information model	The transport sector accounts for a large share of global Co2 emissions. To mitigate the impact of climate change, several sustainability-oriented large-scale infrastructure projects such as electric road systems and expanding rail systems have recently been on the policy agenda. A parallel development that is expected to accelerate the transition of the transport sector is digitalization, which, although ongoing for many decades, has recently been augmented by concepts such as artificial intelligence (AI) and smart city technologies. The integration of these digitalization tools at the organizational level poses not only opportunities but also some challenges for the actors involved in infrastructure projects. An approach that is currently promoted in the infrastructure sector is the Building Information Model (BIM), which is a decision-making instrument that leverages various digitalization tools and applications. However, although the economic implications of BIM are widely discussed in the literature, the (inter-) organizational dynamics involving multiple actors in infrastructure projects are not fully grasped. Large infrastructure projects are sociotechnical endeavors embedded in complex institutional frames, hence the institutional norms, practices and logics in them are significant. Responding to this, this paper adopted an institutional analysis and put the BIM approach in the (inter-) organizational context in infrastructure delivery. Drawing on empirical data from three organizations in infrastructure delivery in Spain, this paper analyzed the tensions among actors during BIM adoption and implementation. © 2020 by the authors.	this paper adopted an institutional analysis and put the BIM approach in the (inter-) organizational context in infrastructure delivery. Drawing on empirical data from three organizations in infrastructure delivery in Spain, this paper analyzed the tensions among actors during BIM adoption and implementation.	The integration of these digitalization tools at the organizational level poses not only opportunities but also some challenges for the actors involved in infrastructure projects. An approach that is currently promoted in the infrastructure sector is the Building Information Model (BIM), which is a decision-making instrument that leverages various digitalization tools and applications.	BIM Case studies, Digital transformation, Institutional logics, Sustainability, digitization, Technology		Analysis	BIM
Ilem I.	2019	Built Environment Project and Asset Management	4	10.1108/BEPAM-05-2018-0077	Adoption of Big Data analytics in construction: development of a conceptual model	Purpose: Big Data (BD) is being increasingly used in a variety of industries including construction. Yet, little research exists that has examined the factors which drive BD adoption in construction. The purpose of this paper is to address this gap in knowledge. Design/methodology/approach: Data collected from literature (55 articles) were analysed using content analysis techniques. Taking a two-pronged approach, first study presents a systematic perspective of literature on BD in construction. Then underpinned by technology–organization–environment theory and supplemented by literature, a conceptual model of five antecedent factors of BD adoption for use in construction is proposed. Findings: The results show that BD adoption in construction is driven by a number of factors: first, technological augmented BD–BIM integration and BD relative advantage, second, organizational: improved design and execution efficiencies, and improved project management capabilities and third, environmental: augmented availability of BD-related technology for construction. Hypothetical relationships involving these factors are then developed and presented through a new model of BD adoption in construction. Research limitations/implications: The study proposes a number of adoption factors and then builds a new conceptual model advancing theories on technologies adoption in construction. Practical implications: Findings will help managers (e.g. chief information officers, IT/IS managers, business and senior managers) to understand the factors that drive adoption of BD in construction and plan their own BD adoption. Results will help policy makers in developing policy guidelines to create sustainable environment for the adoption of BD for enhanced economic, social and environmental benefits. Originality/value: This paper develops a new model of BD adoption in construction and proposes some new factors of adoption process. © 2019, Emerald Publishing Limited.	Purpose: Big Data (BD) is being increasingly used in a variety of industries including construction. Yet, little research exists that has examined the factors which drive BD adoption in construction. The purpose of this paper is to address this gap in knowledge. Design/methodology/approach: Data collected from literature (55 articles) were analysed using content analysis techniques. Taking a two-pronged approach, first study presents a systematic perspective of literature on BD in construction. This paper develops a new model of BD adoption in construction and proposes some new factors of adoption process.	The results show that BD adoption in construction is driven by a number of factors: first, technological augmented BD–BIM integration and BD relative advantage, second, organizational: improved design and execution efficiencies, and improved project management capabilities and third, environmental: augmented availability of BD-related technology for construction. Hypothetical relationships involving these factors are then developed and presented through a new model of BD adoption in construction. Results will help policy makers in developing policy guidelines to create sustainable environment for the adoption of BD for enhanced economic, social and environmental benefits.	Asset management, BIM, Data analysis, Project management Sustainability, Technological innovation		Management	Analytics
Karan E.	2019	Automation in Construction	4	10.1016/j.autcon.2019.02.019	Intelligent designer: A computational approach to automating design of windows in buildings	The process of building design is a means of meeting client expectations for a building, followed by a set of comprehensive standards and codes relating to the design, construction, and maintenance of buildings. The rapidly rising volume of data along with increasing client expectations inspired many researchers to develop new computerized techniques to automate building design process. These techniques can be broken down into two broad categories: automated computer-aided design tools (e.g., development of building information modeling or BIM) and measuring or modeling client expectations (e.g., use of facial expressions to find psychological expectations of the client). Advances in artificial intelligence (AI) and machine learning have made possible new approaches to the automation of design. This represents a shift from a focus on client-designer or designer-technology relationships to a more intelligent and independent client-technology communication. In this paper, a novel AI system called intelligent designer is proposed to understand (or learn) the client's need and expectations and generate valid designs. The design environment (i.e., the interaction between the client and the design) is formulated as a Markov decision process (MDP) and a mathematical framework is provided for making design decisions in situations where new designs are partly random (as they are influenced by the client's feedback) and partly under the control of the computer (as they are influenced by the regulations, standards, and guidelines). The approach is demonstrated using a window design experiment. © 2019	In this paper, a novel AI system called intelligent designer is proposed to understand (or learn) the client's need and expectations and generate valid designs.	The design environment (i.e., the interaction between the client and the design) is formulated as a Markov decision process (MDP) and a mathematical framework is provided for making design decisions in situations where new designs are partly random (as they are influenced by the client's feedback) and partly under the control of the computer (as they are influenced by the regulations, standards, and guidelines). The approach is demonstrated using a window design experiment. © 2019	Artificial intelligence, Automation, Building design, Markov decision process		Design	AI

Pärn E.A.	2019	Facilities	4	10.1108/F-03-2018-0039	Engineering-out hazards: digitising the management working safely in confined spaces	Purpose: This paper aims to report upon the further development of a hybrid application programming interface (API) plug-in to building information modelling (BIM) entitled confined spaces safety monitoring system "CoSMoS". Originally designed to engineer-out environmental hazards associated with working in a building's confined spaces (during the construction phase of a building's life-cycle), this second generation version is expanded upon to use archival records to proactively learn from data generated within a sensor network during the building's operations and maintenance (O&M) phase of asset management (AM). Design/methodology/approach: An applied research methodological approach adopted used a two-phase process. In phase one, a conceptual model was created to provide a "blueprint map" to integrate BIM, sensor-based networks and data analytics (DA) into one integral system. A literature review provided the basis for the conceptual model's further development. In phase two, the conceptual model was transposed into the prototype's development environment as a proof of concept using primary data accrued from a large educational building. Findings: An amalgamation of BIM, historical sensor data accrued and the application of DA demonstrate that CoSMoS provides an opportunity for the facilities management (FM) team to monitor pertinent environmental conditions and human behaviour within buildings that may impact upon occupant/worker safety. Although working in confined spaces is used to demonstrate the inherent potential of CoSMoS, the system could readily be expanded to analyse sensor-based network's historical data of other areas of building performance, maintenance and safety. Originality/value: This novel prototype has automated safety applications for FM during the asset lifecycle and maintenance phase of a building's O&M phase of AM. Future work is proposed in several key areas, namely, develop instantaneous indicators of current safety performance within a building, and develop lead indicators of future safety performance of buildings. © 2019, Emerald Publishing Limited.	Purpose: This paper aims to report upon the further development of a hybrid application programming interface (API) plug-in to building information modelling (BIM) entitled confined spaces safety monitoring system "CoSMoS".	Findings: An amalgamation of BIM, historical sensor data accrued and the application of DA demonstrate that CoSMoS provides an opportunity for the facilities management (FM) team to monitor pertinent environmental conditions and human behaviour within buildings that may impact upon occupant/worker safety. Although working in confined spaces is used to demonstrate the inherent potential of CoSMoS, the system could readily be expanded to analyse sensor-based network's historical data of other areas of building performance, maintenance and safety. Originality/value: This novel prototype has automated safety applications for FM during the asset lifecycle and maintenance phase of a building's O&M phase of AM. Future work is proposed in several key areas, namely, develop instantaneous indicators of current safety performance within a building, and develop lead indicators of future safety performance of buildings. © 2019, Emerald Publishing Limited.	Application programming interface Building information modelling, Confined spaces, Digitalisation, Facilities management Health and safety		Management	BIM
Jeong Y.	2018	Advances in Civil Engineering	4	10.1155/2018/5478381	A study on the BIM evaluation, analytics, and prediction (EAP) framework and platform in linked building ontologies and reasoners with clouds	Rigorous research and practical experience have allowed building information modeling (BIM) to be successfully adopted in the traditional design process without being severely cumbersome. However, there has been less focus on the connectivity and convergence of multiple types of BIM data or even the connectivity among non-BIM data, such as natural language and image/video data. The connectivity of BIM data means more than the syntactical correlations among them. This paper considers how BIM should be redefined to process BIM data as linked semantic data from the perspective of building information management and employ recent advances in the evaluation, analytics, and prediction (EAP) methodology for linked building ontologies and reasoners. © 2018 Yongwook Jeong.	This paper considers how BIM should be redefined to process BIM data as linked semantic data from the perspective of building information management and employ recent advances in the evaluation, analytics, and prediction (EAP) methodology for linked building ontologies and reasoners.	Rigorous research and practical experience have allowed building information modeling (BIM) to be successfully adopted in the traditional design process without being severely cumbersome.			Management	BIM
Singh V.	2016	IFIP Advances in Information and Communication Technology	4	10.1007/978-3-319-54660-5_39	BIM ecosystem research: What, why and how? Framing the directions for a holistic view of BIM	This paper presents theoretical arguments for BIM ecosystem research, based on concepts of coevolution and emergence in a complex network of constituent elements: products, processes, people, technology and policies. Broader trends such as Internet of Things, data analytics, and digital manufacturing are increasingly becoming integral to BIM systems. Consequently, BIM research is evolving along multiple pathways. Therefore, there is need for methodologies and approaches to analyze BIM ecosystem. Three types of ecosystem analyses are proposed: (1) BIM-Ecosystem Retrospective Analysis (BIM-ERA), to understand the ecosystem's constituents and their dependencies, based on facts and history, (2) BIM-Ecosystem Feasibility analysis (BIM-EFA), to be able to use the knowledge of the constituents and their dependencies to assess whether an intended intervention in a given ecosystem is feasible or not, and (3) BIM-Ecosystem Impact Analysis (BIM-EIA), to be able to conduct what-if studies to assess the potential short-term and long-term impact of a potential action. © IFIP International Federation for Information Processing 2016.	This paper presents theoretical arguments for BIM ecosystem research, based on concepts of coevolution and emergence in a complex network of constituent elements: products, processes, people, technology and policies.	Three types of ecosystem analyses are proposed: (1) BIM-Ecosystem Retrospective Analysis (BIM-ERA), to understand the ecosystem's constituents and their dependencies, based on facts and history, (2) BIM-Ecosystem Feasibility analysis (BIM-EFA), to be able to use the knowledge of the constituents and their dependencies to assess whether an intended intervention in a given ecosystem is feasible or not, and (3) BIM-Ecosystem Impact Analysis (BIM-EIA), to be able to conduct what-if studies to assess the potential short-term and long-term impact of a potential action. © IFIP International Federation for Information Processing 2016.	BIM, Coevolution, Ecosystem, Impact analysis, Research methods	Complex networks, Ecology, Constituent elements, Ecosystems, Co-evolution, Digital manufacturing, Ecosystem analysis, Feasibility analysis, Impact analysis, Retrospective analysis, Theoretical arguments, Life cycle	Analysis	BIM
Quinn C.	2020	Automation in Construction	3	10.1016/j.autcon.2020.103257	Building automation system - BIM integration using a linked data structure	Buildings Automation Systems (BAS) are ubiquitous in contemporary buildings, both monitoring building conditions and managing the building system control points. At present, these controls are prescriptive and pre-determined by the design team, rather than responsive to actual building performance. These are further limited by prescribed logic, possess only rudimentary visualizations, and lack broader system integration capabilities. Advances in machine learning, edge analytics, data management systems, and Facility Management-enabled Building Information Models (FM-BIMs) permit a novel approach: cloud-hosted building management. This paper presents an integration technique for mapping the data from a building Internet of Things (IoT) sensor network to an FM-BIM. The sensor data naming convention and time-series analysis strategies integrated into the data structure are discussed and presented, including the use of a 3D nested list to permit time-series data to be mapped to the FM-BIM and readily visualized. The developed approach is presented through a case study describing the scalability of the approach to integrate a building BAS system with a BIM. The resultant data structure and key visualizations are presented to demonstrate the value of this approach, which permits the end-user to select the desired timeframe for visualization and readily step through the spatio-temporal building performance data. © 2020 Elsevier B.V.	This paper presents an integration technique for mapping the data from a building Internet of Things (IoT) sensor network to an FM-BIM. The sensor data naming convention and time-series analysis strategies integrated into the data structure are discussed and presented, including the use of a 3D nested list to permit time-series data to be mapped to the FM-BIM and readily visualized	The developed approach is presented through a case study describing the scalability of the approach to integrate a building BAS system with a BIM. The resultant data structure and key visualizations are presented to demonstrate the value of this approach, which permits the end-user to select the desired timeframe for visualization and readily step through the spatio-temporal building performance data. © 2020 Elsevier B.V.	Building automation systems, FM-BIM integration, Linked data	Automation, Data integration, Data structures, Data visualization, Information management, Enterprise resource planning, Frequency modulation, Intelligent buildings, Internet of things, Linked data, Office buildings, Sensor networks, Time series analysis, Visualization, Building automation systems, Building conditions, Building Information Model - BIM, Building performance, Data management system, Facility management, Integration techniques, Internet of Things (IOT)	Management	BIM
Soman R.K.	2020	Journal of Construction Engineering and Management	3	10.1061/(ASCE)CO.1943-7862.0001846	Codification Challenges for Data Science in Construction	New forms of data science, including machine learning and data analytics, are enabled by machine-readable information but are not widely deployed in construction. A qualitative study of information flow in three projects using building information modeling (BIM) in the late design and construction phase is used to identify the challenges of codification that limit the application of data science. Despite substantial efforts to codify information with common data environment (CDE) platforms to structure and transfer digital information within and between teams, participants work across multiple media in both structured and unstructured ways. Challenges of codification identified in this paper relate to software usage (interoperability, information loss during conversion, multiple modeling techniques), information sharing (unstructured information sharing, drawing and file based sharing, document control bottlenecks, lack of process change), and construction process information (loss of constraints and low level of detail). This paper contributes to the current understanding of data science in construction by articulating the codification challenges and their implications for data quality dimensions, such as accuracy, completeness, accessibility, consistency, timeliness, and provenance. It concludes with practical implications for developing and using machine-readable information and directions for research to extract insight from data and support future automation. © 2020 American Society of Civil Engineers.	This paper contributes to the current understanding of data science in construction by articulating the codification challenges and their implications for data quality dimensions, such as accuracy, completeness, accessibility, consistency, timeliness, and provenance.	It concludes with practical implications for developing and using machine-readable information and directions for research to extract insight from data and support future automation. © 2020 American Society of Civil Engineers.	Artificial intelligence (AI), Automation, Building information modeling (BIM), Codification, Construction, Data science, Data Analytics, Machine readability	Architectural design, Construction, Data Science, Information use, Building Information Model - BIM, Construction process, Data quality dimensions, Design and construction, Digital information, Information sharing, Modelling techniques, Qualitative study, Information dissemination	Design	BIM
Usman M.	2019	Proceedings - MIG 2019: ACM Conference on Motion, Interaction, and Games	3	10.1145/3359566.3360086	Joint exploration and analysis of high-dimensional design–occupancy templates	Crowd simulations provide a practical approach to evaluate building design alternatives with respect to human-centric criteria, such as evacuation times and flow in case of emergency scenarios. Coupled with Building Information Modeling (BIM) tools, they support architects' iterative exploration of design alternatives. However, methods based on manually configuring a design and a corresponding simulation are not practical for exploring the potentially very large number of design solutions that satisfy human-centric design goals and requirements. Often, for practical reasons, designers may consider standard crowd configurations which do not capture the behavior of diverse occupants that may exhibit different locomotion abilities, movement patterns, and social behaviors. We posit that a joint exploration of high-dimensional building design and occupancy features is necessary to more accurately capture the mutual relations between buildings and the behavior of their occupants. To test this hypothesis, we conducted a series of experiments to automatically explore joint high dimensional design–occupancy patterns using an unsupervised pattern recognition technique (i.e. K-MEANS). We demonstrate that joint design–occupancy explorations provide more accurate results compared with sequential exploration processes that consider default design or crowd features, despite the longer computational times to simulate a large number of solutions. The findings of this case study have practical applications to the design of next-generation design exploration tools that support human-centric analyses in architectural design. © 2019 Association for Computing Machinery.	We posit that a joint exploration of high-dimensional building design and occupancy features is necessary to more accurately capture the mutual relations between buildings and the behavior of their occupants. To test this hypothesis, we conducted a series of experiments to automatically explore joint high dimensional design–occupancy patterns using an unsupervised pattern recognition technique (i.e. K-MEANS).	We demonstrate that joint design–occupancy explorations provide more accurate results compared with sequential exploration processes that consider default design or crowd features, despite the longer computational times to simulate a large number of solutions. The findings of this case study have practical applications to the design of next-generation design exploration tools that support human-centric analyses in architectural design. © 2019 Association for Computing Machinery.	Building occupancy, Crowd simulation, Human-centric analytics, Multi-agent systems, Parametric modeling	Iterative methods, Multi agent systems, Building Information Model - BIM, Pattern recognition, Structural design, Building occupancy, Crowd Simulation, Exploration process, Human-centric, Human-centric designs, Parametric modeling, Unsupervised patterns, Architectural design	Design	Analytics
Olbina S.	2019	Buildings	3	10.3390/buildings9080175	Contributing project characteristics and realized benefits of successful BIM implementation: A comparison of complex and simple buildings	Researchers have explored Building Information Modeling (BIM) utilization on complex buildings. However, limited research has been conducted investigating BIM implementation on simple projects. This study explored the perceptions of Architects, General Contractors and Owners regarding the project characteristics that impact successful BIM implementation, and the realized benefits thereof, on complex commercial buildings versus parking garages. A survey comprised of the project characteristics and realized benefits of BIM implementation identified by Dodge Data & Analytics was distributed. Exploratory Factor Analysis was conducted to identify the empirical groupings of successful BIM implementation characteristics and realized benefits thereof. Factor means were calculated and compared using ANOVA and t-tests. Statistical comparisons revealed no significant differences by building type. For project stakeholders, a significant difference was only observed on owner's mean perceptions of technology-related characteristics when compared to architects. Previous research indicates that Architecture, Engineering, and Construction (AEC) stakeholders believe BIM is beneficial for large and complex projects. With the exception of technology-related project characteristics, findings reveal no statistical differences for project characteristics impacting successful BIM utilization or the realized benefits of BIM implementation given building type. This finding provides empirical evidence that various stakeholder groups view BIM as a universal AEC process that provides benefits on both complex and simple projects. © 2019 by the author.	This study explored the perceptions of Architects, General Contractors and Owners regarding the project characteristics that impact successful BIM implementation, and the realized benefits thereof, on complex commercial buildings versus parking garages.	Previous research indicates that Architecture, Engineering, and Construction (AEC) stakeholders believe BIM is beneficial for large and complex projects. With the exception of technology-related project characteristics, findings reveal no statistical differences for project characteristics impacting successful BIM utilization or the realized benefits of BIM implementation given building type. This finding provides empirical evidence that various stakeholder groups view BIM as a universal AEC process that provides benefits on both complex and simple projects. © 2019 by the author.	BIM benefits, BIM Implementation, Exploratory factor analysis, Project stakeholders		Analysis	BIM
Kim J.	2019	Communications in Computer and Information Science	3	10.1007/978-981-13-8410-3_4	Recognizing and Classifying Unknown Object in BIM Using 2D CNN	This paper aims to propose an approach to automated classifying building element instance in BIM using deep learning-based 3D object classification algorithm. Recently, studies related to checking or validating engine of BIM object for ensuring data integrity of BIM instances are getting attention. As a part of this research, this paper train recognition models that are targeted at basic building element and interior element using 3D object recognition technique that uses images of objects as inputs. Object recognition is executed in two stages, (1) class of object (e.g. wall, window, seating furniture, toilet fixture and etc.), (2) sub-type of specific classes (e.g. Toilet or Urinal). Using the trained models, BIM plug-in prototype is developed and the performance of this AI-based approach with test BIM model is checked. We expect this recognition approach to help ensure the integrity of BIM data and contribute to the practical use of BIM. © 2019, Springer Nature Singapore Pte Ltd.	This paper aims to propose an approach to automated classifying building element instance in BIM using deep learning-based 3D object classification algorithm.	Using the trained models, BIM plug-in prototype is developed and the performance of this AI-based approach with test BIM model is checked. We expect this recognition approach to help ensure the integrity of BIM data and contribute to the practical use of BIM. © 2019, Springer Nature Singapore Pte Ltd.	3D object classification Building element, Building information modeling, Data integrity, Interior element	Building components, Image classification, Classification (of information), Deep learning, Object recognition, Structural design, 3d object classifications, 3d object recognition, Building element, Building Information Model BIM, Data integrity, Recognition models, Specific class, Unknown objects, Architectural design	Design	BIM
Selin J.	2018	Proceedings of the 2018 Federated Conference on Computer Science and Information Systems, FedCSIS 2018	3	10.15439/2018F162	The functional design method for buildings (FDM) with gamification of information models and AI help to design safer buildings	We have developed a method that enables better taking into account of need of space of actions of moving objects in a building when Building Information Modeling (BIM) is used. The 3D spatial objects for real space requirements of actions created with our method can be used with various design tools as such in dimensioning or to generate video-game colliders defining the need of space. Together with the gamified model of the structure from BIM they enable dimensioning in designs and simulations. We can dimension spatial objects for example related to safety. There are a lot of needs and applications for our methods. It is possible to design buildings and other structures that fit their purpose well. © 2018 Polish Information Processing Society.	The 3D spatial objects for real space requirements of actions created with our method can be used with various design tools as such in dimensioning or to generate video-game colliders defining the need of space. Together with the gamified model of the structure from BIM they enable dimensioning in designs and simulations. We can dimension spatial objects for example related to safety.	We have developed a method that enables better taking into account of need of space of actions of moving objects in a building when Building Information Modeling (BIM) is used.	Frequency division multiplexing, Information systems, Information theory, Information use, Structural design, Three dimensional computer graphics, Functional design, 3D spatial objects, Building Information Model - BIM, Gamification, Information models, Moving objects, Safer buildings, Spatial objects, Architectural design		Design	AI

Rivest M.	2018	ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and international AEC/FM Hackathon: The Future of Building Things	3	10.22260/isarc2018/0059	Holonic management systems for resilient operation of buildings	Building management systems monitor and control building performances in real-time. Most control systems, which have been developed in the last decade, achieve the required performances relying on a centralised and hierarchical framework. In the regular operation phase, these systems are usually able to efficiently reach their goals, whereas they often fail to stick to pre-determined targets in the presence of unforeseen disturbances. As a matter of fact, traditional control systems suffer complex unforeseen scenarios that cannot be modelled by the analytics and knowledge integrated in these systems, because hierarchical systems strive to keep full control at any level. As an alternative, holonic management systems, which have been successfully applied in the manufacturing field, can tackle this type of drawbacks. The flexibility of their elementary units, the holons, makes it possible to avoid the rigid structure of hierarchical systems so as to respond quickly to disturbances and dynamically re-arrange their structure. In this paper, a first holonic computing structure is developed for indoor comfort management in an office room. The structure developed can drive both the operation management phase and the medium- and long-term measurement of performances. The former is implemented by means of a sequence of specific minimum cost actions which is based on the overall throughput effectiveness (OTE) metrics. The latter exploits the same OTE metrics to suggest corrective and improvement actions. Finally, OTE diagnoses are re-directed to a BIM model to support decision making for long-term improvement actions on the building facility. © ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things. All rights reserved.	In this paper, a first holonic computing structure is developed for indoor comfort management in an office room. The structure developed can drive both the operation management phase and the medium- and long-term measurement of performances.	The former is implemented by means of a sequence of specific minimum cost actions which is based on the overall throughput effectiveness (OTE) metrics. The latter exploits the same OTE metrics to suggest corrective and improvement actions. Finally, OTE diagnoses are re-directed to a BIM model to support decision making for long-term improvement actions on the building facility. © ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things. All rights reserved.	Building Management System, Holonic System, Intelligent buildings	Architectural design, Construction, Control systems, Decision making, Real time systems, Hierarchical systems, Intelligent buildings, Robotics, Building management system, Building performance, Holonic system, Knowledge integrated, Long-term measurements, Manufacturing fields, Operation management, Overall throughput effectiveness, Rigid structures	Management	BIM
Bhargava M.G.	2018	International Journal of Engineering and Technology(UAE)	3		A study on potential of big visual data analytics in construction Arena	In most construction and Infrastructure management projects, it is important to ensure and maintain the performance, safety as well as quality in the work to execute the construction in expected period, for monitoring the above parameters i.e. Performance, Safety, Quality and as well as Security, requires data to analyze, determine and test the algorithms, due to eternal increase amount of captured data thor-ough modern improvements in technology i.e. devices, camera equipped vehicles, Sensors, etc. accommodates an innovative scope to capture present status of construction sites at a less cost analogized to more alternative techniques such as laser scanning technique. Vast endeavours on documenting as-built status, nevertheless, stay at retrieving the visual data and updating Building Information Model (BIM). Hundreds of images and videos are captured but most of the data becomes scrap without proper localize with plan document and time. To take full benefits of visual data for construction status analytics where performance analytics is also included in it, three aspects (reliable, relevance and speed) of capturing, analysing and reporting visual data are captious and tracking development in construction sites needs two direction communication between field crew and management so that performances and changes issues related to task management, completion and outlook can be convey effectively. This paper deals with the investigation of current techniques for influ-ence with help of arising BIM and big data in performance monitoring at construction from reliable, relevance and speed. © 2016 Authors.	This paper deals with the investigation of current techniques for influ-ence with help of arising BIM and big data in performance monitoring at construction from reliable, relevance and speed. © 2016 Authors.	In most construction and Infrastructure management projects, it is important to ensure and maintain the performance, safety as well as quality in the work to execute the construction in expected period sensors,etc. accommodates an innovative scope to capture present status of construction sites at a less cost analogized to more alternative techniques such as laser scanning technique.	Big visual data, Construction performance monitoring, Images, Quality control, Safety			Analysis	BIM
Lin J.J.	2017	Congress on Computing in Civil Engineering, Proceedings	3	10.1061/9780784480830.019	Proactive Construction Project Controls via Predictive Visual Data Analytics	This paper presents a new visual production management system for proactive project controls on construction sites. Taking advantage from the unprecedented growth of visual data on construction sites, the system continuously reconstructs and visualizes reality in form of 4D point clouds and maps it directly within 4D BIM. By putting schedule tasks and project performance data in a visual context for the entire team and mapping Reality to Plan, the system communicates ,who does what work in what location, tracks actual progress and productivity at the weekly work plan and the look ahead schedule, and infers top locations at risk for potential delays. To validate the system and its impact on field reporting and project controls practices, a case study is conducted on a building construction project. Results demonstrate that such a system improves coordination and communication by providing transparency in project execution and helps project teams improve reliability of their short term plans. © 2017 ASCE.	This paper presents a new visual production management system for proactive project controls on construction sites. Taking advantage from the unprecedented growth of visual data on construction sites, the system continuously reconstructs and visualizes reality in form of 4D point clouds and maps it directly within 4D BIM.	Results demonstrate that such a system improves coordination and communication by providing transparency in project execution and helps project teams improve reliability of their short term plans. © 2017 ASCE.	Architectural design, Data Analytics, Human resource management, Predictive analytics, Building construction projects, Construction projects, Project control, Construction sites, Production management systems, Project execution, Project performance, Visual context, Project management		Management	Analytics
Gu Y.	2015	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	3	10.1007/978-3-319-25264-3_39	Conceptual modeling for financial investment with text mining	Although text-mining, sentiment analysis, and other forms of analysis have been carried out on financial investment applications, a significant amount of associated research is ad hoc searching for empirical patterns. Other research in finance develops theory using limited data sets. These efforts are at two extremes. To bridge the gap between financial data analytics and finance domain theory, this research analyzes a specific conceptual model, the Business Intelligence Model (BIM), to identify constructs and concepts that could be beneficial for matching data analytics to domain theory. Doing so, provides a first step towards understanding how to effectively generate and validate domain theories that significantly benefit from data analytics. © Springer International Publishing Switzerland 2015.	this research analyzes a specific conceptual model, the Business Intelligence Model (BIM), to identify constructs and concepts that could be beneficial for matching data analytics to domain theory.	Doing so, provides a first step towards understanding how to effectively generate and validate domain theories that significantly benefit from data analytics. © Springer International Publishing Switzerland 2015	Big data, Business intelligence model (BIM), Conceptual modeling, Domain model, Finance domain theory, Small data, Competitive intelligence, Text-mining	Architectural design, Big data, Finance, Information analysis, Investments, Natural language processing, systems, Conceptual model, Domain model, Domain theory, Small data, Text mining, Data mining	Design	BIM
He R.	2021	Journal of Cleaner Production	2	10.1016/j.jclepro.2020.123505	BIM-enabled computerised design and digital fabrication of industrialised buildings: A case study	Industrialized construction leverages factory-based manufacturing and lean-site assembly to achieve higher industrial efficiency. Building information modelling (BIM) offers new opportunities in the design and prefabrication automation of industrialised buildings, providing greater productivity and cost-effectiveness. In this study, attempts are made to review the state-of-the-art BIM applications on design and prefabrication automation of industrialised buildings, with more emphasis on the recent achievement in concrete 3D printing technology. Following this, a BIM method is proposed to support the detailed geometry design and digital fabrication of modular housings. A program interfaced within BIM is developed and demonstrated through discussions on its capacity in generating the geometry details of 3D-printed modules. In addition, robotic simulation of 3D printing is performed to explore a flexible plan in producing the 3D-printed modules or components. The lessons learned from the study are discussed to highlight the future research challenges and opportunities. First, as current Industry Foundation Classes-based BIM model provides limited support to prefabrication, research on BIM open standards demands more attentions to interoperate the computerised design and computer-aided manufacturing. Moreover, today's industrialised buildings consist of sophisticated architectural, structural, and mechanical systems that are intervened across the whole life cycle, more research on the interdependent building systems is needed (via digital twins) to optimize the life cycle performance. When moving towards data-driven decision making, there are research needs to expand Internet of Things and Artificial Intelligence to collect the big data from prefabrication, perform predictive analysis, and optimize the control decisions for manufacturing facilities operations. This study illustrates the process and future work in BIM design and prefabrication automation that can assist practitioners to enhance the quality of industrialised construction. © 2020 Elsevier Ltd	- In this study, attempts are made to review the state-of-the-art BIM applications on design and prefabrication automation of industrialised buildings, with more emphasis on the recent achievement in concrete 3D printing technology. Following this, a BIM method is proposed to support the detailed geometry design and digital fabrication of modular housings. A program interfaced within BIM is developed and demonstrated through discussions on its capacity in generating the geometry details of 3D-printed modules	This study illustrates the process and future work in BIM design and prefabrication automation that can assist practitioners to enhance the quality of industrialised construction. © 2020 Elsevier Ltd	3D printing, Building information modelling, Computational design, Construction automation, Industrialised building, Prefabrication	3D printers, Computer aided manufacturing, Artificial intelligence, Automation, Cost effectiveness, Decision making, Digital twin, Fabrication, Industrial research, Life cycle, Predictive analytics, Building information Model - BIM, Data driven decision, Industrialised buildings, Industrialised construction, Industry Foundation Classes - IFC, Life-cycle performance, Manufacturing facility, Research challenges	Design	BIM
Abrishami S.	2020	Engineering, Construction and Architectural Management	2	10.1108/ECAM-04-2020-0256	Generative BIM workspace for AEC conceptual design automation: prototype development	Purpose: The integration and automation of the whole design and implementation process have become a pivotal factor in construction projects. Problems of process integration, particularly at the conceptual design stage, often manifest through a number of significant areas, from design representation, cognition and translation to process fragmentation and loss of design integrity. While building information modelling (BIM) applications can be used to support design automation, particularly through the modelling, amendment and management stages, they do not explicitly provide whole design integration. This is a significant challenge. However, advances in generative design now offer significant potential for enhancing the design experience to mitigate this challenge. Design/methodology/approach: The approach outlined in this paper specifically addresses BIM deficiencies at the conceptual design stage, where the core drivers and indicators of BIM and generative design are identified and mapped into a generative BIM (G-BIM) framework and subsequently embedded into a G-BIM prototype. This actively engages generative design methods into a single dynamic BIM environment to support the early conceptual design process. The developed prototype followed the CIFE "horseshoe" methodology of aligning theoretical research with scientific methods to procure architecture, construction and engineering (AEC)-based solutions. This G-BIM prototype was also tested and validated through a focus group workshop engaging five AEC domain experts. Findings: The G-BIM prototype presents a valuable set of rubrics to support the conceptual design stage using generative design. It benefits from the advanced features of BIM tools in relation to illustration and collaboration (coupled with BIM's parametric change management features). Research limitations/implications: This prototype has been evaluated through multiple projects and scenarios. However, additional test data is needed to further improve system veracity using conventional and non-standard real-life design settings (and contexts). This will be reported in later works. Originality/value: Originality and value rest with addressing the shortcomings of previous research on automation during the design process. It also addresses novel computational issues relating to the implementation of generative design systems, where, for example, instead of engaging static and formal description of the domain concepts, G-BIM actively enhances the applicability of BIM during the early design stages to generate optimised (and more purposeful) design solutions. © 2020, Emerald Publishing Limited.	this paper specifically addresses BIM deficiencies at the conceptual design stage, where the core drivers and indicators of BIM and generative design are identified and mapped into a generative BIM (G-BIM) framework and subsequently embedded into a G-BIM prototype. This actively engages generative design methods into a single dynamic BIM environment to support the early conceptual design process.	Findings- The G-BIM prototype presents a valuable set of rubrics to support the conceptual design stage using generative design. It benefits from the advanced features of BIM tools in relation to illustration and collaboration (coupled with BIM's parametric change management features). Research limitations/implications- This prototype has been evaluated through multiple projects and scenarios. However, additional test data is needed to further improve system veracity using conventional and non-standard real-life design settings (and contexts). This will be reported in later works.	AI, Conceptual design, Generative design, Genetic algorithm, Space syntax	Automation, Computer aided design, Building Information Modelling, Conceptual design, Information management, Conceptual design stages, Construction projects, Design and implementations, Design representation, Design/methodology/approach, Generative design methods, Prototype development, Architectural design	Design	BIM
Ferrándiz J.	2019	International Journal of Engineering Education	2		Introducing a new ict tool in an active learning environment course: Performance consequences depending on the introduction design	This paper presents a case-study, quasi-experiment in the framework of Architectural Engineering (AE) Bachelor (BA) degree in the United Arab Emirates University(UAEU)and the Architecture (Arch)BAat the American University of Ras Al Khaimah (AURAK). To analyze the best approach to introduce Building Information Modelling (BIM) tools into Academia, we evaluated three different approaches: by introducing a new BIM tool (Revit) into a construction course. These ICT tools (Information and Communication Technologies), are currently required by the Architectural, Engineering and Construction (AEC) industry. We tested the students' performance, submissions and opinions of the course methods in order to evaluate these approaches. In this study, we compared the students' performance in the Building Components course (BCC) atUAEUand in the Construction II course (CII) at AURAK, analyzing how these new course designs affected the students.Wetested theBCCcourse during six semesters and the CII for two semesters. To achieve a better understanding of the impact of the course on the students, we used the grades of the students to quantify their performance, compared their submissions and interviewed three random students from each semester. There are few studies on the architectural introduction of Revit and BIM into the Architectural curriculum, even though these tools are currently necessary in the Architectural, Engineering and Construction industry. Based on the data obtained from the academic files, the interviews with the students and the analytic study of the data, we created a set of recommendations to introduce Revit into construction courses in the AEC curriculum while preventing a drop in the performance, skills and knowledge acquisition of the students. © 2019 TEMPUS Publications.	This paper presents a case-study, quasi-experiment in the framework of Architectural Engineering (AE) Bachelor (BA) degree in the United Arab Emirates University(UAEU)and the Architecture (Arch)BAat the American University of Ras Al Khaimah (AURAK). To analyze the best approach to introduce Building Information Modelling (BIM) tools into Academia, we evaluated three different approaches:by introducing a new BIM tool (Revit) into a construction course.	There are few studies on the architectural introduction of Revit and BIM into the Architectural curriculum, even though these tools are currently necessary in the Architectural, Engineering and Construction industry. Based on the data obtained from the academic files, the interviews with the students and the analytic study of the data, we created a set of recommendations to introduce Revit into construction courses in the AEC curriculum while preventing a drop in the performance, skills and knowledge acquisition of the students. © 2019 TEMPUS Publications.	academic analytics, architectural engineering, BIM, curriculum, educational assessment, Revit, Construction industry, student performance	Computer aided instruction, Construction, Curricula, Students, academic analytics, Architectural engineering, Educational assessment, Revit, Student performance, Academic analytics, Architectural design	Design	BIM
Klomann M.	2018	Proceedings of the 2017 23rd International Conference on Virtual Systems and Multimedia, VSMM 2017	2	10.1109/VSMM.2017.8346289	NetFlinCS: A hybrid cloud-based framework to allow context-based detection and surveillance	In this paper, we present the NetFlinCS framework, which allows a fast and effective development of compute-intensive interactive applications for mobile devices using hybrid cloud technologies. In addition, we show its advantages by using the proposed technology to build a context-based detection and surveillance application for construction sites, which aggregates all relevant data during architecture planning and the construction process for documentation and later use in facility management. The NetFlinCS framework enables rich Mixed Reality techniques like sensor fusion over multiple mobile devices or AI-based recognition as well as the integration of databases to enable an automatic detection of discrepancies based on common tracking technologies. The device uses the location awareness to process the camera stream in the context of the local planning data. To reduce the client's workload as well as for better scalability and to enable the heavy use of machine learning techniques, we use a hybrid cloud environment that consists of all available servers and clients to outsource expensive calculations. The hybrid cloud backend provides different services like machine learning based segmentation, inpainting, and scene classification that support navigation, video processing, and error estimation in real-time. By deeply integrating standard data formats like the Industry Foundation Classes standard and Building Information Modeling it is possible to compare these databases with tracking data to detect and localize discrepancies over the whole life cycle of a building, from planning data (blueprints, architectural models, etc.) up to the real building. © 2017 IEEE.	In this paper, we present the NetFlinCS framework, which allows a fast and effective development of compute-intensive interactive applications for mobile devices using hybrid cloud technologies. In addition, we show its advantages by using the proposed technology to build a context-based detection and surveillance application for construction sites, which aggregates all relevant data during architecture planning and the construction process for documentation and later use in facility management.	The hybrid cloud backend provides different services like machine learning based segmentation, inpainting, and scene classification that support navigation, video processing, and error estimation in real-time. By deeply integrating standard data formats like the Industry Foundation Classes standard and Building Information Modeling it is possible to compare these databases with tracking data to detect and localize discrepancies over the whole life cycle of a building, from planning data (blueprints, architectural models, etc.) up to the real building.	Artificial intelligence, Learning systems, Life cycle, Mixed reality, Mobile devices, Office buildings, Building Information Model - BIM, Video signal processing, Architectural models, Industry foundation classes standard, Interactive applications, Machine learning techniques, Scene classification, Standard data format, Surveillance applications, Information management		Management	AI

Ahi C.	2018	ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things	2	10.22260/isarc2018/0005	Supporting post-occupant evaluation through work order evaluation and visualization in FM-BIM	The application of BIM and data analytics in facility management is an area of growing interest and research. The ability to mine data from occupant complaints in real-time and visualize this at the building and building cluster scale provides new opportunities for facility managers to more effectively respond to occupant complaints and optimize the performance of the building. A project is currently underway at Ryerson University in collaboration with the facility management team to mine data from work orders and develop a comprehensive visualization strategy for FM-BIM integration. This paper presents the development of mapping and data visualization strategies to support the identification of priority areas and extraction of key occupant satisfaction trends. Key visualizations and BIM integration protocols from the campus deployment are presented and discussed to identify applicability of this data to support post-occupancy evaluation, limitations, and opportunities for further expansion and refinement. © ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things. All rights reserved.	This paper presents the development of mapping and data visualization strategies to support the identification of priority areas and extraction of key occupant satisfaction trends. Key visualizations and BIM integration protocols from the campus deployment are presented and discussed to identify applicability of this data to support post-occupancy evaluation, limitations, and opportunities for further expansion and refinement.	The ability to mine data from occupant complaints in real-time and visualize this at the building and building cluster scale provides new opportunities for facility managers to more effectively respond to occupant complaints and optimize the performance of the building.	BIM, Facility management, Operations & maintenance, Post-occupant evaluation, Visualization, Work order	Construction, Data visualization, Data Analytics, Data integration, Flow visualization, Frequency modulation, Human resource management, Information management, Office buildings, Robotics, Visualization, BIM integrations, Cluster scale, Facility management, Facility managers, Occupant satisfaction, Post occupancy evaluation, Post-occupant evaluation, Work order	Management	BIM
Bigham G.F.	2018	Advances in Intelligent Systems and Computing	2	10.1007/978-3-030-01057-7_76	Artificial intelligence for construction safety: Mitigation of the risk of fall	Technology is continually being implemented by construction professionals with the goal of improving construction processes and the industry's glacial pace of change. As we look to new technologies to solve existing problems, we can consider Artificial Intelligence (AI) as a tool to make construction safer and efficient. Through this paper, we explore the ways in which AI can assist in the goal of making construction sites safe. This study proposes the development of an AI platform, which improves construction safety through hazard identification at the pre-construction stage, and suggests the applicable OSHA codes for the identified hazards, thus allowing safety standards to be implemented for compliance. Emphasis is laid on the mitigation of fall hazards, which is the leading cause of accidents in construction. Currently, project safety and risk assessment in the construction industry is carried out by professionals, who heavily rely on their own experiences and knowledge on decision making. There is a lack of a systematic approach and the ways to check the reliability of these decisions. Through the machine learning aspect of AI, we can automate the process and create an environment where potential hazards are identified before they occur with a link to the OSHA standards for recommended mitigation strategies. © Springer Nature Switzerland AG 2019.	Through this paper, we explore the ways in which AI can assist in the goal of making construction sites safe. This study proposes the development of an AI platform, which improves construction safety through hazard identification at the pre-construction stage, and suggests the applicable OSHA codes for the identified hazards, thus allowing safety standards to be implemented for compliance.	Through the machine learning aspect of AI, we can automate the process and create an environment where potential hazards are identified before they occur with a link to the OSHA standards for recommended mitigation strategies. © Springer Nature Switzerland AG 2019.	Artificial Intelligence, BIM, Fall protection, OSHA, Safety	Accident prevention, Artificial intelligence, Decision making, Construction, Construction industry, Hazards, Learning systems, Regulatory compliance, Risk assessment, Construction process, Construction professionals, Construction safety, Fall protection, Hazard identification, Mitigation strategy, OSHA, Safety and risk assessment, Architectural design	Design	AI
Khairuzaman H.A.	2018	International Journal of Engineering and Technology(UAE)	2	10.14419/ijet.v7i4.35.23096	Automation in civil engineering design in assessing building energy efficiency	Automation in Civil Engineering design is no longer unfamiliar anymore in the construction industry. It brings great efficiency gains and has reduced many of the complicated aspects of design. Automation has been developing since over the last four decades where advancement of computer hardware and in line with software developments has enabled various sort of design to be computerized. The design process is now more fast and accurate, and the entire process has been outstandingly improved by the available technology. However, the problems related to computerized design, started from the possibilities for unrecognized or unanticipated consequences as the design becomes more complicated. In line with it is the global warming issue that has been threatening the human being. Therefore, this paper reviews the design automation and its application in civil engineering design emphasizing in assessing the energy efficiency of buildings, which includes background information, its application, advantages, and challenges and also suggestions to further improve the automation in civil engineering design by artificial intelligence (AI). It was discovered that since over the past few years, BIM implementation in Civil Engineering design has started to be adopted massively in construction industry due to its tremendous advantages. In this paper, a new flow process in design automation in assessing building sustainability has been proposed by implementing AI BIM which is linked with MyCREST, a green rating tool in Malaysia in order to assist designers to conceptually design for a more energy efficient building. © 2018 Authors.	this paper reviews the design automation and its application in civil engineering design emphasizing in assessing the energy efficiency of buildings, which includes background information, its application, advantages, and challenges and also suggestions to further improve the automation in civil engineering design by artificial intelligence (AI).	It was discovered that since over the past few years, BIM implementation in Civil Engineering design has started to be adopted massively in construction industry due to its tremendous advantages. In this paper, a new flow process in design automation in assessing building sustainability has been proposed by implementing AI BIM which is linked with MyCREST, a green rating tool in Malaysia in order to assist designers to conceptually design for a more energy efficient building. © 2018 Authors.	Artificial Intelligence, Automation, Building information modelling, Civil engineering design, Energy efficiency		Design	AI
Lu W.	2017	Comprehensive Geographic Information Systems	2	10.1016/B978-0-12-409548-9.09677-9	The Fusion of GIS and Building Information Modeling for Big Data Analytics in Managing Development Sites	Due to increasing complexity of contemporary site development, more information about sites themselves and their related environmental, geographical, and surrounding infrastructure is highly desired to support informed decision-making. Fusion of Geographic Information Systems (GIS) and Building Information Modeling (BIM) to support decision-making in site development has gained momentum from both academia and practitioners. Nevertheless, innovative applications of GIS and BIM integration are yet to be fully explored. Using several cases in Hong Kong Special Administrative Region (SAR), this article demonstrates how to integrate GIS and BIM to derive big data for decision-making in construction logistics and supply chain management (LSCM) and construction waste management in site development. In addition, this article proposes a conceptual framework of integrating BIM and GIS for better site development and urban management. The cases in this article not only shed light on big data analytics in a site development setting but also provide useful references to GIS and BIM fusion for better urban management. © 2018 Elsevier Inc. All rights reserved.	this article demonstrates how to integrate GIS and BIM to derive big data for decision-making in construction logistics and supply chain management (LSCM) and construction waste management in site development.	this article proposes a conceptual framework of integrating BIM and GIS for better site development and urban management. The cases in this article not only shed light on big data analytics in a site development setting but also provide useful references to GIS and BIM fusion for better urban management. © 2018 Elsevier Inc. All rights reserved.	Big data, Building Information Modeling (BIM), Built environment, Construction management, Construction waste management (CWM), Cyber-physical system, Hong Kong, Decision-making, Geographic Information Systems (GIS), Information management, Logistic and supply-chain management (LSCM), Smart construction objectives, Urbanization		Management	BIM
Hanley B.P.	2016	IET Conference Publications	2	10.1049/cp.2016.1432	Putting asset data at the heart of organisational decision-making using an Integrated Workplace Management System	With the advent of "Big Data" and the "Internet of Things", traditional approaches to asset management are being continually challenged and superseded by innovative technology solutions. These enable organisations to improve operational efficiency, strengthen stakeholder relations and reduce costs. Given current economic pressures, the coincidence of technological and economic pressures is driving a step change in how organisations operate. To adopt to the changing technology landscape, organisations need to take a strategic approach around how they manage their information. A core component of this can be an Integrated Workplace Management Systems (IWMS), which provides a single technology platform that organisations can firstly use to create accurate records of their reference data (which include buildings, assets, people, and contracts). Secondly, organisations can use the integral process engines within the IWMS to manage business processes (for example contract management, preventative / reactive maintenance tasks, project management, facilities assessments, strategic planning, and environmental reporting). Organisations that have implemented an IWMS have experienced significant operational benefits, through more efficient business processes, better stakeholder relationships, reduced operating costs, improved productivity and clearly demonstrable legal compliance. With a single data repository, transparent reference data, and comprehensive analytics, organisations can embrace a new generation of key performance indicators to commend differential advantage in their competitive environments. However, implementing an IWMS requires a strategic approach to implementation, which must align to business process change and strong data governance. It should be noted that whilst this paper has been produced by employees of IBM, who provide IWMS capabilities and associated consulting services, the paper and its associated presentation are not a sales pitch for IBM solutions. There are many technology platforms and capabilities that align to this paper's description of an IWMS and the associated challenges and benefits. © 2016 Institution of Engineering and Technology. All rights reserved.	A core component of this can be an Integrated Workplace Management Systems (IWMS), which provides a single technology platform that organisations can firstly use to create accurate records of their reference data (which include buildings, assets, people, and contracts). Secondly, organisations can use the integral process engines within the IWMS to manage business processes (for example contract management, preventative / reactive maintenance tasks, project management, facilities assessments, strategic planning, and environmental reporting).	Organisations that have implemented an IWMS have experienced significant operational benefits, through more efficient business processes, better stakeholder relationships, reduced operating costs, improved productivity and clearly demonstrable legal compliance. It should be noted that whilst this paper has been produced by employees of IBM, who provide IWMS capabilities and associated consulting services, the paper and its associated presentation are not a sales pitch for IBM solutions. There are many technology platforms and capabilities that align to this paper's description of an IWMS and the associated challenges and benefits. © 2016 Institution of Engineering and Technology. All rights reserved.	Asset management, Assets, Big data, BIM, Integrated workplace management system, Internet of Things, Maintenance, IoT, IWMS, Portfolio management, Predictive analytics, Real estate, Strategy, Systems	Architectural design, Asset management, Behavioral research, Benchmarking, Big data, Computer systems, Cost reduction, Financial data processing, Information management, Information services, Internet of things	Management	Analytics
El-Diraby T.	2016	Transforming the Future of Infrastructure through Smarter Information - Proceedings of the International Conference on Smart Infrastructure and Construction, ICSIC 2016	2	10.1680/tfisi.61279.551	Green2.0: Socio-Technical analytics of green buildings	Professionals and researchers of the AEC (Architectural, Engineering & Construction) industry, as well as, public policy makers are challenged by the increasing complexity and need to improve our understanding of the social, technical and business dimensions of green building projects. This typically requires close cooperation of the design team, the architects, the engineers, and the rest of the stakeholders at all project stages, but most importantly availability of new methods, tools and strategies that are enabled by emerging technologies. This paper builds around an online platform (Green2.0), that tries to leverage advancements in Building Information Models (BIM), energy-efficiency simulation tools and online social network analysis methods to enable a data-driven approach to building design, planning, construction and maintenance. The platform advances the current state of the art by providing an online integrated environment for (a) efficient storage, indexing, querying, 3D visualization and exploration of BIMs, (b) sharing BIMs and enabling online collaboration among the various stakeholders (c) interactive energy efficiency analysis of buildings by automatically linking IFC to external energy simulation libraries, and (d) interactive analysis of patterns of social interactions and collaboration networks of AEC professionals. © The authors and ICE Publishing: All rights reserved, 2016.	This paper builds around an online platform (Green2.0), that tries to leverage advancements in Building Information Models (BIM), energy-efficiency simulation tools and online social network analysis methods to enable a data-driven approach to building design, planning, construction and maintenance.	The platform advances the current state of the art by providing an online integrated environment for (a) efficient storage, indexing, querying, 3D visualization and exploration of BIMs, (b) sharing BIMs and enabling online collaboration among the various stakeholders (c) interactive energy efficiency analysis of buildings by automatically linking IFC to external energy simulation libraries, and (d) interactive analysis of patterns of social interactions and collaboration networks of AEC professionals. © The authors and ICE Publishing: All rights reserved, 2016.	Buildings, Complex networks, Construction, Digital storage, Energy efficiency, Social networking (online), Data-driven approach, Three dimensional computer graphics, Collaboration network, Emerging technologies, Green building projects, Integrated environment, Interactive analysis, On-line collaborations, On-line social networks, Architectural design		Design	Analytics
Yu Y.	2013	Journal of Asian Architecture and Building Engineering	2	10.3130/jaabe.12.189	A study on the model of a building-envelope structural modification system to increase energy efficiency at the schematic design stage	The purpose of this study was to create a building-envelope structural modification system (BESMS) and an accompanying algorithm that could be used to improve a building's energy efficiency. The proposed system is capable of deciding the optimal structure of a building-envelope. Methods adopted in the study include a review of previous studies and reference literature and, interviews with relevant industry experts. As part of creating the BESMS and algorithm, a five-stage building-envelope design process (BEDP) offering a basis for the BESMS was established. A model using BIM-based design software programs as platforms was proposed as well. The decision-making system for designing the proposed model was developed by combining the FLSs (AI technique) and AHP (decision-making method). Based on these outcomes, components of the BESMS were defined, an inference-deciding structure was determined for each decision-making item as required by the BESMS, related design factors were identified, and the degree of importance was calculated. Lastly, using these results, the model for the BESMS was created.	The purpose of this study was to create a building-envelope structural modification system (BESMS) and an accompanying algorithm that could be used to improve a building's energy efficiency. The proposed system is capable of deciding the optimal structure of a building-envelope	Based on these outcomes, components of the BESMS were defined, an inference-deciding structure was determined for each decision-making item as required by the BESMS, related design factors were identified, and the degree of importance was calculated. Lastly, using these results, the model for the BESMS was created.	Algorithm, Building envelope, Energy efficiency, Fuzzy logic, Schematic design	Algorithms, Decision making, Solar buildings, Energy efficiency, Fuzzy logic, Structural optimization, Building envelope design, Building envelopes, Decision-making method, Decision-making systems, Design softwares, Optimal structures, Schematic design, Structural modifications, Architectural design	Design	BIM
Xue F.	2021	Advanced Engineering Informatics	1	10.1016/j.aei.2020.101245	Semantic enrichment of building and city information models: A ten-year review	Building Information Models (BIMs) and City Information Models (CIMs) have flourished in building and urban studies independently over the past decade. Semantic enrichment is an indispensable process that adds new semantics such as geometric, non-geometric, and topological information into existing BIMs or CIMs to enable multidisciplinary applications in fields such as construction management, geoinformatics, and urban planning. These two paths are now coming to a juncture for integration and juxtaposition. However, a critical review of the semantic enrichment of BIM and CIM is missing in the literature. This research aims to probe into semantic enrichment by comparing its similarities and differences between BIM and CIM over a ten-year time span. The research methods include establishing a uniform conceptual model, and sourcing and analyzing 44 pertinent cases in the literature. The findings plot the terminologies, methods, scopes, and trends for the semantic enrichment approaches in the two domains. With the increasing availability of data sources, algorithms, and computing power, they cross the border to enter each other's domain. Future research will likely gain new momentums from the demands of value-added applications, development of remote sensing devices, intelligent data processing algorithms, interoperability between BIM and CIM software platforms, and emerging technologies such as big data analytics. © 2021 Elsevier Ltd	This research aims to probe into semantic enrichment by comparing its similarities and differences between BIM and CIM over a ten-year time span. The research methods include establishing a uniform conceptual model, and sourcing and analyzing 44 pertinent cases in the literature	The findings plot the terminologies, methods, scopes, and trends for the semantic enrichment approaches in the two domains. With the increasing availability of data sources, algorithms, and computing power, they cross the border to enter each other's domain. Future research will likely gain new momentums from the demands of value-added applications, development of remote sensing devices, intelligent data processing algorithms, interoperability between BIM and CIM software platforms, and emerging technologies such as big data analytics. © 2021 Elsevier Ltd	Building Information Model, City Information Model, Geographic Information System, Intelligent building, Semantic enrichment, Smart city	Advanced Analytics, Data handling, Application programs, Data Analytics, Information theory, Project management, Remote sensing, Semantics, Building Information Model - BIM, Construction management, Emerging technologies, Intelligent data processing, Semantic enrichment, Software platforms, Topological information, Value added applications, Architectural design	Analysis	BIM
Chew M.Y.L.	2020	Sustainability (Switzerland)	1	10.3390/su12410259	Evaluating the roadmap of 5g technology implementation for smart building and facilities management in singapore	The concepts of smart building (SB) and smart facilities management (SFM) are crucial as they aim to uplift occupants' living standards through information and communication technology. However, the current network possesses several challenges to SFM, due to low bandwidth, high latency, and inability to connect a high amount of IoT (Internet of things) devices. 5G technology promises high-class network services with low latency, high bandwidth, and network slicing to achieve real-time efficiency. Moreover, 5G promises a more sustainable future as it will play a crucial role in reducing energy consumption and shaping future applications to achieve higher sustainability goals. This paper discusses the current challenges and benefits of implementing 5G in various use cases in SFM applications. Furthermore, this paper highlights the Singapore government rollout plan for 5G implementation and discusses the roadmap of SFM use case development initiatives undertaken by 5G Advanced BIM Lab (Department of Building, National University of Singapore) in alignment with the 5G implementation plan of Singapore. Under these 5G SFM projects, the lab seeks to develop state-of-the-art 5G use cases in collaboration with various industry partners and developed a framework for teaching and training to enhance students' learning motivation and help mid-career professionals to upskill and upgrade themselves to reap multiple benefits using the 5G network. This article will serve as a benchmark for researchers and industries for future progress and development of SFM systems by leveraging 5G networks for higher sustainability targets and implementing teaching and learning programs to achieve greater organizational excellence. © 2020 by the authors. Licensee MDPI, Basel, Switzerland.	This paper discusses the current challenges and benefits of implementing 5G in various use cases in SFM applications. Furthermore, this paper highlights the Singapore government rollout plan for 5G implementation and discusses the roadmap of SFM use case development initiatives undertaken by 5G Advanced BIM Lab (Department of Building, National University of Singapore) in alignment with the 5G implementation plan of Singapore.	This article will serve as a benchmark for researchers and industries for future progress and development of SFM systems by leveraging 5G networks for higher sustainability targets and implementing teaching and learning programs to achieve greater organizational excellence. © 2020 by the authors. Licensee MDPI, Basel, Switzerland.	5G technology, AI, AR/VR, BIM, Drone, Smart building, communication network, Smart facilities management	benchmarking, building consumption behavior, information and communication technology, learning, sustainability, teaching, Singapore	Management	BIM

Bloch T.	2020	Journal of Computing in Civil Engineering	1	10.1061/(ASCE)CP.1943-5487.0000922	Clustering Information Types for Semantic Enrichment of Building Information Models to Support Automated Code Compliance Checking	Missing, incomplete, implicit, and/or incorrect information are major obstacles to automated code compliance checking in the construction industry. All existing platforms for automated code checking require users to extensively preprocess their input models to supplement missing information before checking can begin. Semantic enrichment using artificial intelligence (AI) can automate much of this normalization process. Progress in the field of semantic enrichment, in turn, requires identification and specification of the information types that must be made explicit, and of the procedures appropriate for each type. After characterizing a broad set of clauses from five diverse building codes, a two-stage clustering process with the k-means algorithm was used to derive a hierarchical classification of semantic enrichment task types. The resulting classification defines 10 tasks that are typically needed for automated code compliance checking. Future research can build on the classification to formalize a knowledge base to inform selection of appropriate approaches for semantic enrichment tasks. © 2020 American Society of Civil Engineers.	Missing, incomplete, implicit, and/or incorrect information are major obstacles to automated code compliance checking in the construction industry. All existing platforms for automated code checking require users to extensively preprocess their input models to supplement missing information before checking can begin. Semantic enrichment using artificial intelligence (AI) can automate much of this normalization process.	After characterizing a broad set of clauses from five diverse building codes, a two-stage clustering process with the k-means algorithm was used to derive a hierarchical classification of semantic enrichment task types. The resulting classification defines 10 tasks that are typically needed for automated code compliance checking.	Automated code compliance checking, Building information modeling (BIM), Clustering, Semantic enrichment, Unsupervised learning	Artificial intelligence, Automation, Hierarchical clustering, Building codes, Construction industry, K-means clustering, Knowledge based systems, Semantics, Building Information Model - BIM, Clustering information, Hierarchical classification, Information types, Missing information, Normalization process, Semantic enrichment, Two-stage clustering, Compliance control	Analysis	BIM
Demirdöğen G.	2020	Sustainability (Switzerland)	1	10.3390/su12177061	Lean management framework for healthcare facilities integrating BIM, BEPS and big data analytics	An increase in the usage of information and communication technologies (ICT) and the Internet of Things (IoT) in Facility Management (FM) induces a huge data stack. Even though these data bring opportunities such as cost savings, time savings, increase in user comfort, space optimization, energy savings, inventory management, etc., these data sources cannot be managed and manipulated effectively to increase efficiency at the FM stage. In addition to data management issues, FM practices, or developed solutions, need to be supported with the implementation of lean management philosophy to reveal organizational and managerial wastes. In the literature, some researchers performed studies about awareness about building information modeling (BIM)-FM, and FM-related data management problems in terms of lean philosophy. However, the comprehensive solution for effective FM has not been investigated with the application of lean management philosophy yet. Therefore, this study aims to develop an FM framework for healthcare facilities by considering lean management philosophy since more stable workflow, continuous improvement, and creating more value to customers will help to deliver a more acceptable solution for the FM industry. Within this context, the integration of BIM, Building Energy Performance Simulations, and Big Data Analytics are proposed as a solution. In the study, the Design Science Research (DSR) methodology was followed to develop the FM framework. Depending on the DSR methodology, two scenarios were used to investigate the issue in a real healthcare facility and develop the FM framework. The developed framework was evaluated by four experts, and the revisions of the proposed framework were realized. © 2020 by the authors.	Therefore, this study aims to develop an FM framework for healthcare facilities by considering lean management philosophy since more stable workflow, continuous improvement, and creating more value to customers will help to deliver a more acceptable solution for the FM industry.	Within this context, the integration of BIM, Building Energy Performance Simulations, and Big Data Analytics are proposed as a solution. In the study, the Design Science Research (DSR) methodology was followed to develop the FM framework. Depending on the DSR methodology, two scenarios were used to investigate the issue in a real healthcare facility and develop the FM framework. The developed framework was evaluated by four experts, and the revisions of the proposed framework were realized. © 2020 by the authors.	Big data analytics (BDA), Building energy performance simulations (BEPS), Building information modeling (BIM)	analytical method, communication network, data management, energy efficiency, inventory, health care, Internet, optimization, organizational framework, philosophy	Management	BIM
Abbasi A.A.	2020	Construction Management and Economics	1	10.1080/01446193.2019.1623409	Conceptualising and operationalising team task interdependences: BIM implementation assessment using effort distribution analytics	Building Information Modelling (BIM) is a technological innovation currently at the forefront of digital transformation in the built environment. To achieve satisfactory outcomes with BIM, adopters need to find the most appropriate implementation strategy that is economically efficient. The research discussed here explores why and how distribution of effort spent on various tasks over project life cycle can be used as a metric for assessing and improving the performance of BIM implementation. Using quantitative data collected from a single in-depth case study of a BIM-enabled design and build project and subsequent interviews with three project actors and 11 BIM experts, to validate and triangulate the findings, we explore the use of effort data to analyze and visualize effort distribution patterns. The visualizations revealed the dynamics of team collaboration and task interdependence in BIM-enabled work and their impact on effort distribution. Lack of timely input by the contractor, subcontractors and suppliers influenced unusual patterns in the distribution of efforts indicating potential sources of inefficiency and unnecessary costs in the BIM process, thereby revealing the pivotal role of procurement structure and suggesting the need for timely involvement of key project participants. The contribution of this work is twofold. Methodologically, effort distribution analytics can provide insights that managers can use to improve BIM implementation process. Theoretically, the findings can be used to support informed decision-making, control cost, optimize resources, manage cash flow and to structure fees. © 2019, © 2019 Informa UK Limited, trading as Taylor & Francis Group.	The research discussed here explores why and how distribution of effort spent on various tasks over project life cycle can be used as a metric for assessing and improving the performance of BIM implementation.	The contribution of this work is twofold. Methodologically, effort distribution analytics can provide insights that managers can use to improve BIM implementation process. Theoretically, the findings can be used to support informed decision-making, control cost, optimize resources, manage cash flow and to structure fees. © 2019, © 2019 Informa UK Limited, trading as Taylor & Francis Group.	Building information modelling, construction, effort distribution, performance assessment, team collaboration	Construction, Decision making, Contractors, Costs, Information theory, Life cycle, Building Information Modelling, Distribution of efforts, effort distribution, Implementation process, Implementation strategies, Performance assessment, Team collaboration, Technological innovation, Architectural design, building, conceptual framework, construction industry, construction method	Design	BIM
Eber W.	2020	Organization, Technology and Management in Construction	1	10.2478/otmcj-2020-0002	Potentials of artificial intelligence in construction management	Artificial intelligence (AI) approaches have been developed since the upcoming of Information Technologies beginning in the 1950s. With rising computing power, the discussion of AI usefulness has been refuelled by new powerful algorithms and, in particular, the availability of the internet as a vast resource of unstructured data. as self-determined subsystem, located outside of hierarchical control. At this point algorithms of AI need to be investigated not so much as to substitute human mind but to provide significant support. © 2020 Wolfgang Eber, published by Sciendo.	Artificial intelligence (AI) approaches have been developed since the upcoming of Information Technologies beginning in the 1950s. With rising computing power, the discussion of AI usefulness has been refuelled by new powerful algorithms and, in particular, the availability of the internet as a vast resource of unstructured data. as self-determined subsystem, located outside of hierarchical control.	With rising computing power, the discussion of AI usefulness has been refuelled by new powerful algorithms and, in particular, the availability of the internet as a vast resource of unstructured data. as self-determined subsystem, located outside of hierarchical control.	Artificial intelligence, Building Information Model (BIM), Complexity, Construction management, Coordination, Organisation Real-estate management		Management	AI
Noran O.	2020	IOEIS 2020 - Proceedings of the 22nd International Conference on Enterprise Information Systems	1		Situation-aware building information models for next generation building management systems	Technical advances in Information and Communication Technology have enabled the collection and storage of large amounts of data, rising hopes of improving asset decision-making and related building management support systems. It appears however that the gap between the required decision-making knowledge and the actual useful information provided by current technologies appears to increase, rather than contract. Thus, often the multitude of patterns afforded by current data analytics techniques does not deliver a set of scenarios prone to effective decision making. This paper advocates a decision analytics solution featuring the use of Situated Logic to create 'narratives' providing adequate meaning to data analytics results, and the use of Channel Theory so as to support adequate situational awareness. This approach is also analysed in the context of a Building Management System-of-Systems paradigm, highly relevant to the emerging complex Clusters of Intelligent Buildings within Smart Cities, featuring collaborative decision-making centres and their associated decision support systems. Copyright © 2020 by SCITEPRESS - Science and Technology Publications, Lda. All rights reserved.	This paper advocates a decision analytics solution featuring the use of Situated Logic to create 'narratives' providing adequate meaning to data analytics results, and the use of Channel Theory so as to support adequate situational awareness.	Technical advances in Information and Communication Technology have enabled the collection and storage of large amounts of data, rising hopes of improving asset decision-making and related building management support systems. It appears however that the gap between the required decision-making knowledge and the actual useful information provided by current technologies appears to increase, rather than contract.	Big Data, Building Information Model, Building Management System of Systems, Channel Theory, Data Warehousing, Decision Model, Situational Awareness	Data Analytics, Decision Support Systems, Situated Reasoning, Decision support systems, Decision theory, Digital storage, Information management, Information systems, Information use, Intelligent buildings, System of systems, Building Information Model - BIM, Building management, Building management system, Collaborative decision making, Current technology, Information and Communication Technologies, Large amounts of data	Management	BIM
Wong J.-Y.	2020	International Journal of Interactive Mobile Technologies	1	10.3991/IJIM.V14I06.13397	BIM-VR framework for building information modelling in engineering education	With the advancement of information technology, Building Information Modeling (BIM) is evolving fast and play an essential role in Architecture, Engineering, Construction, Owner and Operators (AECOO) industry. Universities play an important role in the current BIM transition in construction projects as well as to embrace Industry 4.0. In this research, immersive Virtual Reality (VR) in BIM offer a unique, supportive environment for the user experience in visualizing and collecting data from the model. With Virtual Reality (VR), engineering education has a major breakthrough. Immersive interactions, stereoscopic 3D, real time multisensory simulations, virtual explorations, synchronous communications, data analytics and visual analysis-all these are impossible without VR. VR offers a student-centred learning environment that promotes active and collaborative learning, situated within simulated real-world contexts. © 2020 International Association of Online Engineering.	In this research, immersive Virtual Reality (VR) in BIM offer a unique, supportive environment for the user experience in visualizing and collecting data from the model. With Virtual Reality (VR), engineering education has a major breakthrough. Immersive interactions, stereoscopic 3D, real time multisensory simulations, virtual explorations, synchronous communications, data analytics and visual analysis-all these are impossible without VR	VR offers a student-centred learning environment that promotes active and collaborative learning, situated within simulated real-world contexts. © 2020 International Association of Online Engineering.	BIM-VR framework, Engineering education, Virtual reality		Analysis	BIM
Gradeci K.	2019	Construction Innovation	1	10.1108/CI-07-2019-0057	On the potential of integrating building information modelling (BIM) for the additive manufacturing (AM) of concrete structures	Purpose: Additive manufacturing (AM) and building information modelling (BIM) are emerging trends for which it has been claimed that both increase both efficiency and productivity in the construction industry. This study aims to synthesise and aggregate the literature addressing BIM integration in the AM of concrete structures and to exploit the joint value creation potential. Design/methodology/approach: This study firstly applies a mixed-review method to achieve mutual corroboration and interdependency between quantitative and qualitative research approaches. Bibliometric mapping is applied to identify, map and synthesise the relevant literature. Scoping review is used to examine the extent, gap, range and nature of the research activity. Afterward, a cross-situational analysis, the threats, opportunities, weaknesses and strengths2 matrix, is proposed and applied to exploit the joint value creation potential of different aspects of AM and BIM. Findings: The study reveals a substantial interest in this field. However, progress in terms of integration is slow compared to the rapid development in interest in the two trends individually. The literature discusses or conceptualises such integration at building-scale, while prototyping or proof-of-concept processes are only rarely used. The study identified 12 joint value creation potentials through the integration of BIM in AM for concrete structures, which can create value by enabling more optimised designs, automated construction processes and data analytics that can apply throughout the building life-cycle process. Originality/value: The advancements of BIM integration in the AM of concrete structures are analysed and joint value creation potentials are proposed. The study proposes a cross-situation analysis that can be applied to structure joint value creation potentials from the multi-dimensional integration of different factors and topics, especially for emerging technologies. © 2019, Emerald Publishing Limited.	This study aims to synthesise and aggregate the literature addressing BIM integration in the AM of concrete structures and to exploit the joint value creation potential. Design/methodology/approach: This study firstly applies a mixed-review method to achieve mutual corroboration and interdependency between quantitative and qualitative research approaches	Findings: The study reveals a substantial interest in this field. However, progress in terms of integration is slow compared to the rapid development in interest in the two trends individually. The literature discusses or conceptualises such integration at building-scale, while prototyping or proof-of-concept processes are only rarely used. The study identified 12 joint value creation potentials through the integration of BIM in AM for concrete structures, which can create value by enabling more optimised designs, automated construction processes and data analytics that can apply throughout the building life-cycle process.	3D printing, Additive manufacturing, Autonomous construction, BIM, Concrete, Digital transformation	3D printers, Concrete buildings, Additives, Concrete aggregates, Concrete construction, Concrete products, Concretes, Construction industry, Data Analytics, Information theory, Integration, Life cycle, 3-D printing, Automated construction, Autonomous constructions, Building Information Modelling, Design/methodology/approach, Digital transformation, Emerging technologies	Management	BIM
Marzouk M.	2019	Built Environment Project and Asset Management	1	10.1108/BEPAM-04-2018-0069	Analyzing project data in BIM with descriptive analytics to improve project performance	Purpose: The purpose of this paper is to expand the benefits of building information modelling (BIM) to include data analytics to analyze construction project performance. BIM is a great tool which improves communication and information flow between construction project parties. This research aims to integrate different types of data within the BIM environment, then, to perform descriptive data analytics. Data analytics helps in identifying hidden patterns and detecting relationships between different attributes in the database. Design/methodology/approach: This research is considered to be an inductive research that starts with an observation of integrating BIM and descriptive data analytics. Thus, the project's correspondence, daily progress reports and inspection requests are integrated within the project 5D BIM model. Subsequently, data mining comprising association analysis, clustering and trend analysis is performed. The research hypothesis is that descriptive data analytics and BIM have a great leverage to analyze construction project performance. Finally, a case study for a construction project is carried out to test the research hypothesis. Findings: The research finds that integrating BIM and descriptive data analytics helps in improving project communication performance, in terms of integrating project data in a structured format, efficiently retrieving useful information from project raw data and visualizing analytics results within the BIM environment. Originality/value: The research develops a dynamic model that helps in detecting hidden patterns and different progress attributes from construction project raw data. © 2019, Emerald Publishing Limited.	The purpose of this paper is to expand the benefits of building information modelling (BIM) to include data analytics to analyze construction project performance. BIM is a great tool which improves communication and information flow between construction project parties. This research aims to integrate different types of data within the BIM environment, then, to perform descriptive data analytics.	Findings: The research finds that integrating BIM and descriptive data analytics helps in improving project communication performance, in terms of integrating project data in a structured format, efficiently retrieving useful information from project raw data and visualizing analytics results within the BIM environment.	Association analysis, Big data, Building information modelling, Data analytics, Data clustering, Trend analysis		Analysis	BIM
Musella C.	2019	Proceedings of the International fib Symposium on Conceptual Design of Structures	2		BIM & AI: Advanced technologies for the digitalisation of seismic damages in masonry buildings	The research reports on the achievements using two digital technologies, such as Building Information Modelling (BIM) and Artificial Intelligence (AI) in the field of damage detection and assessment of masonry buildings. The purpose of the work is to point out the potentials and the benefits for the assessment and the automatic digitization of target buildings affected by hazard induced damages. To this scope, the photogrammetry technique is used to fit with the implementation of on-site visual data into the technologies previously mentioned. The final aim is to speed up the way of approaching intervention strategies on existing buildings that are becoming obsolete in relation to the technological progress of the building sector. © Fédération Internationale du Béton – International Federation for Structural Concrete.	The final aim is to speed up the way of approaching intervention strategies on existing buildings that are becoming obsolete in relation to the technological progress of the building sector. © Fédération Internationale du Béton – International Federation for Structural Concrete.	The research reports on the achievements using two digital technologies, such as Building Information Modelling (BIM) and Artificial Intelligence (AI) in the field of damage detection and assessment of masonry buildings.	Conceptual design, Damage detection, Masonry construction, Masonry materials, Advanced technology, Building Information Modelling, Intervention strategy, Building sectors, Digital technologies, Masonry building, Research reports, Technological progress, Architectural design		Design	BIM
Chang C.-H.	2019	Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation - Selected Papers from the ASCE International Conference on Computing in Civil Engineering 2019	1	10.1061/9780784482421.025	Applying Deep Learning and Building Information Modeling to Indoor Positioning Based on Sound	At present, indoor positioning has great potential for disaster mitigation, such as guiding evacuees to safe places. This research aims at developing such a sound-based method using artificial intelligence (AI) and building information modeling (BIM). Amid a disaster, first responders can quickly set up the proposed system to help indoor positioning, which relies on BIM, virtual reality (VR), and head related transfer functions (HRTF) techniques to simulate virtual sound fields. Then, a deep learning model is trained so as to be able to predict the current zone within a room based on the sound received. Unity, a serious game platform, and Steam Audio, a Unity plugin designed for adding 3D audio to VR experience, are employed to generate input data sets. The overall accuracy of the output results is about 90% though the training time is long, which can be reduced if more powerful computing resources are utilized. © 2019 American Society of Civil Engineers.	This research aims at developing such a sound-based method using artificial intelligence (AI) and building information modeling (BIM). Amid a disaster, first responders can quickly set up the proposed system to help indoor positioning, which relies on BIM, virtual reality (VR), and head related transfer functions (HRTF) techniques to simulate virtual sound fields.	Then, a deep learning model is trained so as to be able to predict the current zone within a room based on the sound received. Unity, a serious game platform, and Steam Audio, a Unity plugin designed for adding 3D audio to VR experience, are employed to generate input data sets. The overall accuracy of the output results is about 90% though the training time is long, which can be reduced if more powerful computing resources are utilized. © 2019 American Society of Civil Engineers.	Acoustic fields, Architectural design, Disasters, Indoor positioning systems, Information theory, Serious games, Visualization, Sound reproduction, Virtual reality, Building information Model - BIM, Computing resource, Disaster mitigation, First responders, Head related transfer function, Indoor		Design	BIM

Talamo C.	2019	Springer Tracts in Civil Engineering	1	10.1007/978-3-030-04009-3_8	FM Services Procurement and Management: Scenarios of Innovation	The present chapter introduces some scenarios of innovation of FM practices, namely: Sustainable Procurement, Building Information Modeling (BIM), Big Data and Internet of Things (IoT). These innovations are described in detail and then discussed with respect to the elaboration of ITTs, analyzing the contents that consequently will have to be reviewed and added by the Client. Firstly, an overview of the Sustainable Procurement introduced by the international standard ISO 20400:2017 is provided, highlighting its principles, core subjects and drivers, as well as benefits and advantages. Then, the active measures for the integration of sustainable procurement practices within the steps constituting the traditional procurement process are described and analyzed. Secondly, the chapter introduces BIM as a promising technology for the innovation of the FM sector, highlighting its main features and capabilities—including visualization, interoperability and information exchange—useful to enhance collaboration among FM stakeholders and to streamline FM processes and activities, at the strategic, tactical and operational levels. Lastly, the chapter focuses on Big Data and IoT paradigms and their application to FM, highlighting how the availability of real-time data—gathered by a distributed and disseminated system of IoT sensors and devices implemented within the building—along with the capabilities of Big Data Analytics, may represent a significant driver for improving the monitoring and control processes of service performance, as well as for FM-related cognitive and decision-making processes, gaining the needed awareness useful to properly calibrate future choices and investments. © 2019, Springer Nature Switzerland AG.	The present chapter introduces some scenarios of innovation of FM practices, namely: Sustainable Procurement, Building Information Modeling (BIM), Big Data and Internet of Things (IoT).	Lastly, the chapter focuses on Big Data and IoT paradigms and their application to FM, highlighting how the availability of real-time data—gathered by a distributed and disseminated system of IoT sensors and devices implemented within the building—along with the capabilities of Big Data Analytics	Big data, Building Information Modeling (BIM), Internet of Things (IoT), IoT platform, IoT sensors and devices, Sustainable procurement		Management	BIM
Macrozob Semnani N.	2018	ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	1	10.5194/isprs-annals-IV-4-133-2018	Towards an intelligent platform for big 3d geospatial data management	The use of intelligent technologies within 3D geospatial data analysis and management will decidedly open the door towards efficiency, cost transparency, and on-time schedules in planning processes. Furthermore, the mission of smart cities as a future option of urban development can lead to an environment that provides high-quality life along stable structures. However, neither geospatial information systems nor building information modelling systems seem to be well prepared for this new development. After a review of current approaches and a discussion of their limitations we present our approach on the way to an intelligent platform for the management and analysis of big 3D geospatial data focusing on infrastructure projects such as metro or railway tracks planning. three challenges are presented focusing on the management of big geospatial data with existing geo-database management systems, the integration of heterogeneous data, and the 3D visualization for database query formulation and query results. The approach for the development of a platform for big geospatial data analysis is discussed. Finally, we give an outlook on our future research supporting intelligent 3D city applications in the United Arab Emirates. © 2018 Authors.	We present our approach on the way to an intelligent platform for the management and analysis of big 3D geospatial data focusing on infrastructure projects such as metro or railway tracks planning. three challenges are presented focusing on the management of big geospatial data with existing geo-database management systems, the integration of heterogeneous data, and the 3D visualization for database query formulation and query results.	The approach for the development of a platform for big geospatial data analysis is discussed. Finally, we give an outlook on our future research supporting intelligent 3D city applications in the United Arab Emirates.	3D Geodatabase, Big Geospatial Data, BIM, Geo-Data Management, Intelligent Geospatial Data Analytics		Management	BIM
Liu N.	2018	IOT Conference Publications	1	10.1049/cp.2018.1731	Current trend in planning and scheduling of construction project using artificial intelligence	During digitalization of Architecture, Engineering and Construction (AEC) industry, one of the influential technologies, Computer-Aided Design can present the state of these digital technologies that assist practitioners to achieve better work. Similar with CAD, digital project planning and schedule control approaches are still mainly relayed on expert experiences which leads to high expert cost in construction project. Researchers and construction-related project participants develops technologies related to Artificial Intelligence (AI) field to decrease the dependence level of expert in construction planning and schedule control. This paper focuses on 1) teasing out the historical trend in planning and scheduling of construction project of AI technologies, 2) using published construction projects and interview data collected by authors, introducing the current trend of implementation of AI technologies in construction planning and schedule control area. Then, this paper identified gaps of AI technologies adoption between academic perspective and real world in both construction scheduling and planning areas. This paper collected totally 1120 journal papers, by keywords as: Artificial Intelligence, Construction. Then the papers are selected following criterion that after 2000 and only related to relevant research fields. After paper selection, totally 383 papers are analysed to identify the historical trend. © 2018 Institution of Engineering and Technology. All rights reserved.	This paper focuses on 1) teasing out the historical trend in planning and scheduling of construction project of AI technologies, 2) using published construction projects and interview data collected by authors, introducing the current trend of implementation of AI technologies in construction planning and schedule control area.	Then, this paper identified gaps of AI technologies adoption between academic perspective and real world in both construction scheduling and planning areas.	4D CAD ARTIFICIAL INTELLIGENCE, BIM, CONSTRUCTION MANAGEMENT, SCHEDULING	Artificial intelligence, Health care, Biomedical engineering, Computer aided design, Robotics, Scheduling, Architectural engineering and construction industries, Construction management, Construction planning, Construction projects, Construction scheduling, Digital technologies, Planning and scheduling, Project participants, Architectural design	Management	AI
Behnam A.	2016	MATEC Web of Conferences	1	10.1051/matecconf/20166600101	Construction management scheduling and control: The familiar historical overview	The paper suggests that 'management by exception' is an historical default control mechanism based on the perception of control as a static process. However, increasingly scholars claim that a dynamic and proactive systems model is a more effective form of project control. These findings are the result of an historical desktop research method that analysed content from a small sample of scheduling methods and control approaches found in online and university library resources. The concept of control has historically influenced both visualization and analytics of different scheduling methods for construction project management. This paper focuses on two control ideals, static and dynamic control mechanisms. The overview begins with the description of early graphical scheduling techniques: Gantt charts and Harmonogram. It continues with examples of contributors to scheduling and control that include: CPM, PERT, LOB, Flowline and Location Based Management. The finding of this simple history suggests that change is the constant element for project control mechanisms. An object-based digital environment such as the data-rich building information modelling (BIM) appears to be continuing the change for new scheduling methods and control mechanisms. © 2016 The Authors.	This paper focuses on two control ideals, static and dynamic control mechanisms. The overview begins with the description of early graphical scheduling techniques: Gantt charts and Harmonogram.	The finding of this simple history suggests that change is the constant element for project control mechanisms. An object-based digital environment such as the data-rich building information modelling (BIM) appears to be continuing the change for new scheduling methods and control mechanisms.	Architectural design Dynamics, Libraries, Project management, Building information Modeling, Digital environment, Construction management, Construction project management, Dynamic control mechanisms, Scheduling and controls, Scheduling techniques, University libraries, Scheduling		Management	BIM
Nalchigar S.	2014	Lecture Notes in Business Information Processing	1	10.1007/978-3-662-45501-2_18	Towards actionable business intelligence: can system dynamics help?	Business intelligence (BI) and data analytics provide modern enterprises with insights about internal operations, performance, as well as environmental trends, and enable them to make data-driven decisions. Insights resulting from these systems often suggest several alternative changes or corrective actions within the enterprise. In this context, to trade-off and find the most proper action(s) is a non-trivial task due to existing dynamics and complexities of the enterprise. This paper proposes a model-based approach to support the analysis and selection of best alternative actions in adaptive enterprise contexts. The proposed approach links and synthesizes two existing modeling frameworks, the Business Intelligence Model (BIM) and System Dynamics, in a systematic step-by-step way to assist decision makers in finding best response action(s) from a given set of alternatives, and hence to make BI more actionable and understandable. The applicability of this approach in illustrated in a scenario adapted from literature. © IFIP International Federation for Information Processing 2014.	This paper proposes a model-based approach to support the analysis and selection of best alternative actions in adaptive enterprise contexts.	The proposed approach links and synthesizes two existing modeling frameworks, the Business Intelligence Model (BIM) and System Dynamics, in a systematic step-by-step way to assist decision makers in finding best response action(s) from a given set of alternatives, and hence to make BI more actionable and understandable.	Analytics, Business Intelligence, Enterprise Modeling, Goal-oriented Requirements Engineering, Simulation, System Dynamics	Competitive intelligence, Requirements engineering, Decision making, Economic and social effects, System theory, Analytics, Enterprise modeling, Goal-oriented requirements engineering, Simulation, System Dynamics, Information analysis	Analysis	Analytics
Ryu M.	2021	Journal of Big Data		10.1186/s40537-021-00417-x	Understanding quality of analytics trade-offs in an end-to-end machine learning-based classification system for building information modeling	Optimizing quality trade-offs in an end-to-end big data science process is challenging, as not only do we need to deal with different types of software components, but also the domain knowledge has to be incorporated along the process. This paper focuses on methods for tackling quality trade-offs in a common data science process for classifying Building Information Modeling (BIM) elements, an important task in the architecture, engineering, and construction industry. Due to the diversity and richness of building elements, machine learning (ML) techniques have been increasingly investigated for classification tasks. However, ML-based classification faces many issues, w.r.t. vast amount of data with heterogeneous data quality, diverse underlying computing configurations, and complex integration with industrial BIM tools, in an end-to-end BIM data analysis. In this paper, we develop an end-to-end ML classification system in which quality of analytics is considered as the first-class feature across different phases, from data collection, feature processing, training to ML model serving. We present our method for studying the quality of analytics trade-offs and carry out experiments with BIM data extracted from Solibri to demonstrate the automation of several tasks in the end-to-end ML classification. Our results have demonstrated that the quality of data, data extraction techniques, and computing configurations must be carefully designed when applying ML classifications for BIM in order to balance constraints of time, cost, and prediction accuracy. Our quality of analytics methods presents generic steps and considerations for dealing with such designs, given the time, cost, and accuracy trade-offs required in specific contexts. Thus, the methods could be applied to the design of end-to-end BIM classification systems using other ML techniques and cloud services. © 2021, The Author(s).	This paper focuses on methods for tackling quality trade-offs in a common data science process for classifying Building Information Modeling (BIM) elements, an important task in the architecture, engineering, and construction industry.	In this paper, we develop an end-to-end ML classification system in which quality of analytics is considered as the first-class feature across different phases, from data collection, feature processing, training to ML model serving.	Building information modeling, Classification, Data analysis, Machine learning, Quality of analytics		Analysis	BIM
Chen B.	2021	Journal of Cleaner Production		10.1016/j.jclepro.2021.126153	Multiobjective optimization of building energy consumption based on BIM-DB and LSSVM-NSGA-II	The building envelope performance significantly influences the building energy consumption, and the major influencing factors of the building envelope include the external wall U-value, external wall solar absorptance, roof U-value, roof solar absorptance, external window U-value, and window-to-wall ratio. This paper proposed a framework that integrates Building Information Modeling (BIM) with LSSVM (least square support vector machine (LSSVM) and non-dominated sorting genetic algorithm-II (NSGA-II)) to study the influence of building envelope parameters on building energy consumption and discover the best design. The DesignBuilder (DB) is used to perform energy consumption simulation and orthogonal experiment to obtain the sample data set. The LSSVM is utilized to learn the data set to establish a prediction model between the building envelope and energy consumption, which is used as the fitness function of the building energy consumption in NSGA-II. With the objective of minimizing building energy consumption and maximizing the indoor thermal comfort (measured by predicted mean vote or PMV), an NSGA-II multi-objective optimization model is established. The Pareto front is obtained through calculation, and the optimal combination of building envelope parameters is discovered using the ideal point method. A case of a proposed school building in China is used to demonstrate the feasibility and effectiveness of the developed framework, the results show that: (1) The LSSVM has great ability to predict building energy consumption, achieving an accurate prediction with a goodness-of-fit of 0.9549 and an RMSE of 0.0271, (2) The optimized envelope design parameters of the proposed building are presented, including the External wall U-value is 0.2, the External wall solar absorptance is 0.55, the Roof U-value is 0.2, the External window U-value is 0.4166, the External window U-value is 1, the Window-wall ratio is 0.215. (3) The developed LSSVM-NSGA II hybrid approach can effectively improve the building's energy consumption and thermal comfort with the building energy consumption reduced by 10.6% and the thermal comfort increased by 32.2% than the initial values, respectively. The proposed LSSVM-NSGA II framework is able to optimize building envelope design parameters than its precedent, which can provide effective thinking for similar problems. © 2021	This paper proposed a framework that integrates Building Information Modeling (BIM) with LSSVM (least square support vector machine (LSSVM) and non-dominated sorting genetic algorithm-II (NSGA-II)) to study the influence of building envelope parameters on building energy consumption and discover the best design.	The proposed LSSVM-NSGA II framework is able to optimize building envelope design parameters than its precedent, which can provide effective thinking for similar problems.	Building energy consumption Energy consumption simulation and prediction, LSSVM, Multi-objective optimization, NSGA-II, Forecasting, Thermal comfort	Energy conservation, Energy utilization, Genetic algorithms, Multiobjective optimization, Predictive analytics, Roofs, Solar buildings, Structural design, Support vector machines, Thermal comfort, Walls (structural partitions), Building energy consumption, Building envelope design, Building envelope performance, Building Information Model - BIM, Least square support vector machines, Multi-objective optimization models	Management	BIM
Seghezzi E.	2021	Applied Sciences (Switzerland)		10.3390/app11073108	Towards an occupancy-oriented digital twin for facility management: Test campaign and sensors assessment	This study focuses on calibration and test campaigns of an IoT camera-based sensor system to monitor occupancy, as part of an ongoing research project aiming at defining a Building Management System (BMS) for facility management based on an occupancy-oriented Digital Twin (DT). The research project aims to facilitate the optimization of building operational stage through advanced monitoring techniques and data analytics. The quality of collected data, which are the input for analyses and simulations on the DT virtual entity, is critical to ensure the quality of the results. Therefore, calibration and test campaigns are essential to ensure data quality and efficiency of the IoT sensor system. The paper describes the general methodology for the BMS definition, and method and results of first stages of the research. The preliminary analyses included Indicative Post-Occupancy Evaluations (PODs) supported by Building Information Modelling (BIM) to optimize sensor system planning. Test campaign are then performed to evaluate collected data quality and system efficiency. The method was applied on a Department of Politecnico di Milano. The period of the year in which tests are performed was critical for lighting conditions. In addition, spaces' geometric features and user behavior caused major issues and faults in the system. © 2021 by the authors.	The research project aims to facilitate the optimization of building operational stage through advanced monitoring techniques and data analytics.	The paper describes the general methodology for the BMS definition, and method and results of first stages of the research.	Asset management, Building management system, Digital twin, Facility management, Post-occupancy evaluations		Management	AI
La Russa F.M.	2021	Journal of Archaeological Science: Reports		10.1016/j.jasrep.2020.102735	An AI-based DSS for preventive conservation of museum collections in historic buildings	The study deals with the experimentation of innovative and advanced preservation methodologies for museum collections in historical buildings. In particular, this work shows the development of an algorithm, based on Machine Learning techniques, that suggests which actions to undertake in relation to thermo-hygrometric conditions. The aim is to guarantee microclimate conditions that are favorable both for collections and architecture. In order to boost the time required to gather the needed dataset a possibility is to train the decision-making model based on machine learning through the use of a synthetic dataset created via plugins connected to VPL (Visual Programming Languages) that allow the simulation of different scenarios starting from open source data. The training of the machine learning mechanism will be supervised and each solution will be "an experience" for the building from which to learn. Along the time thanks to experience and background data the decision-making system will improve the quality of his work. © 2020 Elsevier Ltd	The study deals with the experimentation of innovative and advanced preservation methodologies for museum collections in historical buildings. In particular, this work shows the development of an algorithm, based on Machine Learning techniques, that suggests which actions to undertake in relation to thermo-hygrometric conditions. The aim is to guarantee microclimate conditions that are favorable both for collections and architecture.	The training of the machine learning mechanism will be supervised and each solution will be "an experience" for the building from which to learn. Along the time thanks to experience and background data the decision-making system will improve the quality of his work.	Architectural survey, Artificial intelligence, DSS, H-BIM, Museum collections, Preventive conservation, VPL		Analysis	BIM

Aragao R.	2021	Automation in Construction		10.1016/j.autcon.2020.103512	Network analytics and social BIM for managing project unstructured data	Unstructured data, mainly text in project documents and final evaluation or summary reports, is a container of tacit knowledge. We present an exploratory case study to use semantic network analysis to help capture and formalize elements of this knowledge. Text from project documents and chats by project participants over an interactive BIM platform were collected and arranged in the form of concept networks. With that, we used the rich literature in network science to formally study the networks. We illustrate the proposed approach by analyzing five concept networks. The case study illustrates the benefits of the approach—mainly, to develop a project-specific map of key concepts. Using network measures, such as centrality, identified the project's key issues and how they relate. Clustering measures identified possible knowledge constructs (interrelated concepts). Measures for quantifying the overall structure of the network can also be used to contrast projects. © 2020 Elsevier B.V.	We present an exploratory case study to use semantic network analysis to help capture and formalize elements of this knowledge.	The case study illustrates the benefits of the approach—mainly, to develop a project-specific map of key concepts.	Blockmodeling, Construction management, Energy use, Knowledge retrieval and representation, Network analysis, Unstructured data	Knowledge representation, Exploratory case studies, Semantics, Concept networks, Managing projects, Network measures, Project documents, Project participants, Semantic network analysis, Unstructured data, Architectural design	Management	BIM
Li W.	2021	Journal of Ambient Intelligence and Humanized Computing		10.1007/s12652-020-02668-7	The effectiveness of project management construction with data mining and blockchain consensus	The Artificial Intelligence (AI) middle office, Blockchain (BC) technology, and Building Information Modeling (BIM) technology are applied to manage construction projects, thereby solving the trust problems during construction project management and optimizing the management model of construction project quality. The construction project of a university in Guangdong Province, China, is adopted as a case to discusses the disputes between the stakeholders of the construction projects in terms of contract and construction claims, as well as exploring the material price forecast, cost, and schedule, thereby verifying the effectiveness of the method proposed during the project management. The results indicate that AI middle office can provide evidence support for stakeholders. Especially during the claim, AI middle office can define the accountability and analyze data when forecasting prices, thereby providing stakeholders with data support. If the BC technology is utilized to input, process, and export relevant program files and price data, the accuracy and safety of the data will be guaranteed. When the progress and cost indicators are analyzed, the results of using this technology are more accurate than the original results, which saves the cost. Therefore, applying AI technology, BC technology, and BIM technology to manage construction projects is of great significance for improving the efficiency and quality of project management. © 2021, Springer-Verlag GmbH Germany, part of Springer Nature.	The Artificial Intelligence (AI) middle office, Blockchain (BC) technology, and Building Information Modeling (BIM) technology are applied to manage construction projects, thereby solving the trust problems during construction project management and optimizing the management model of construction project quality.	Therefore, applying AI technology, BC technology, and BIM technology to manage construction projects is of great significance for improving the efficiency and quality of project management. © 2021, Springer-Verlag GmbH Germany, part of Springer Nature. The results indicate that AI middle office can provide evidence support for stakeholders. Especially during the claim, AI middle office can define the accountability and analyze data when forecasting prices, thereby providing stakeholders with data support	Artificial intelligence, Blockchain technology, Consensus mechanism, Project management	Architectural design, Artificial intelligence, Blockchain, AI, Technologies, Costs, Data mining, BIM technologies, Building Information Model - BIM, Construction claim, Construction project management, Construction projects, Guangdong Province, Management Model, Project management	Management	Analytics
Zhou Q.	2021	Advances in Intelligent Systems and Computing		10.1007/978-981-33-4572-0_233	Construction Collaborative Management Method Based on BIM and Control Calculation	BIM Technology is an important method to solve the problem of coordination in the construction process of engineering projects. The construction project construction collaborative management method combined with control computing can be visualized in real-time and can dynamically control the calculation and simulation process. Through the analysis of the important role of the combination of control type calculation and BIM for construction collaborative management, the application of based on BIM theory, engineering collaborative management theory, and multi-objective optimization theory, the multi-objective optimization model based on IFC is established, and the combination scheme of control computing, convolutionary algorithm, and BIM is designed to realize the calculation of multi-objective optimization model. The collaborative management model of the construction stage is constructed to integrate the multi-objective optimization process and the collaborative workflow of all participants in the construction stage. The construction collaborative model can effectively realize the collaborative work among the participants in the construction stage, the collaborative optimization of multi-objective, and the real-time visualization and real-time control of the process. © 2021, The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd.	Through the analysis of the important role of the combination of control type calculation and BIM for construction collaborative management, the application of based on BIM theory, engineering collaborative management theory, and multi-objective optimization theory, the multi-objective optimization model based on IFC is established, and the combination scheme of control computing, convolutionary algorithm, and BIM is designed to realize the calculation of multi-objective optimization model.	The construction collaborative model can effectively realize the collaborative work among the participants in the construction stage, the collaborative optimization of multi-objective, and the real-time visualization and real-time control of the process.	BIM, Collaborative management, Construction management, Control computing	Advanced Analytics, Architectural design, Big data, Multiobjective optimization, Computation theory, Embedded systems, Project management, Real time control, Smart city, Co-evolutionary algorithm, Collaborative management, Collaborative optimization, Collaborative workflow, Construction process, Construction projects, Multi-objective optimization models, Real time visualization, Process control	Management	BIM
Peng L.	2021	Advances in Intelligent Systems and Computing		10.1007/978-981-33-4572-0_56	The Application Practice of BIM Technology in Prefabricated Building Design	The so-called prefabricated building is actually a building system that integrates design, production, construction, decoration, supervision and other links, so it always presents a strong integration characteristic. The BIM technology, which is the main line that integrates many of the above elements, especially after the organization of simulation activities such as informatization collaborative design, visual assembly, node interactive connection and inspection, it can be more quickly and conveniently integrated, and dynamic supervision and management. The entire industrial chain of prefabricated buildings avoids repeated signs of errors in the design. To apply BIM technology in prefabricated building can effectively improve the effectiveness of prefabricated building design, and it is convenient for engineering designers to discover the deficiencies in prefabricated building design in time and make timely corrections. © 2021, The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd.	To apply BIM technology in prefabricated building can effectively improve the effectiveness of prefabricated building design, and it is convenient for engineering	designers to discover the deficiencies in prefabricated building design in time and make timely corrections	Application practice, Architectural design, BIM, Construction, Prefabricated	Advanced Analytics, Big data, Smart city, Embedded systems, Prefabricated construction, BIM technologies, Building systems, Collaborative design, Engineering design, Industrial chain, Informatization, Architectural design	Design	BIM
Yu I.	2021	Advances in Intelligent Systems and Computing		10.1007/978-3-030-62746-1_48	Effective Control Method of the Whole Process Project Cost Based on BIM	Engineering industry is one of the important industries in the process of economic development. In the aspect of project investment, how to achieve the expected effect with the minimum investment under the premise of ensuring the project quality has become the topic of common concern of all stakeholders. In view of the difficulty of the traditional project cost control which is not refined and time-consuming, this paper proposes an effective control method of the whole process of the project, so as to realize effective management and avoid out of control investment. Through the actual case, the results show that the method presented in this paper has obvious advantages in time consumption and estimation accuracy, and the satisfaction of management personnel, construction personnel and supervision personnel has reached more than 85%. © 2021, The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG.	In view of the difficulty of the traditional project cost control which is not refined and time-consuming, this paper proposes an effective control method of the whole process project cost based on BIM. BIM technology is used to control the cost of the whole process of the project, so as to realize effective management and avoid out of control investment	Through the actual case, the results show that the method presented in this paper has obvious advantages in time consumption and estimation accuracy, and the satisfaction of management personnel, construction personnel and supervision personnel has reached more than 85%.	BIM (Building Information Modeling), Cost control, Effect evaluation, Whole process engineering management	Architectural design, Big data, Economics, Investments, Human resource management, Internet of things, Machine learning, Privacy by design, BIM technologies, Construction personnel, Control methods, Effective management, Engineering industries, Expected effects, Project quality, Time consumption, Advanced Analytics	Management	BIM
Cai S.	2021	Lecture Notes in Civil Engineering		10.1007/978-3-030-51295-8_72	Trends of Research and Development on Construction Robotics Considering the Supporting Technologies and Successful Applications	Although construction robotics has been researched and developed over the past decades and the practical needs keep rising, its application remains limited. This study is aimed at exploring the trends of research and development (R&D) on construction robotics based on a thorough investigation of the numerous existing publications and case studies of successful applications in this field. First, a scientometric review is conducted to identify and discuss the supporting technologies with significant contributions in the field during the past decades and their trends, as well as the hottest ones at present. Then case studies on two Chinese construction companies that developed and applied robotic products successfully are presented to reveal how the supporting technologies were implemented in practices and how the R&D and application were followed up. The hottest supporting technologies at present were found to be computer vision, 3D printing, Building Information Modeling (BIM), and Artificial Intelligence (AI), as well as their emerging branches including Simultaneous Localization and Mapping (SLAM), machine learning, and deep learning. Three critical factors were identified for the follow-up of the R&D of construction robotics, i.e., mutual promotion between the R&D and application of construction robot products and the development of supporting technologies, asynchronous development in different application areas, and multidisciplinary cooperation among construction companies and professional technological companies. The findings are expected to be valuable for the related stakeholders including researchers, robot developers, and construction companies to conduct further R&D and application of robotics in the construction industry. © 2021, The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG.	This study is aimed at exploring the trends of research and development (R&D) on construction robotics based on a thorough investigation of the numerous existing publications and case studies of successful applications in this field.	The findings are expected to be valuable for the related stakeholders including researchers, robot developers, and construction companies to conduct further R&D and application of robotics in the construction industry.	Case study, Construction robotics, Scientometric literature review	3D printers, Construction, Construction industry, Deep learning, Robots, Engineering education, Robotics, Building Information Model - BIM, Construction companies, Construction robotics, Construction robots, ITS applications, Research and development, Simultaneous localization and mapping, Supporting technology, Architectural design	Design	AI
Carvalho W.O.	2021	Lecture Notes in Civil Engineering		10.1007/978-3-030-51295-8_49	BIM and AM to Manage Critical and Relevant Water and Wastewater Utilities Assets	Global Water and Sewage Utilities must manage a wide variety of essential infrastructure assets while meeting complex social and environmental challenges, and this is especially true in Brazil, where according to SNIS Institute only 53% of the population has sewerage coverage and 17% still does not have access to treated water [14]. The Brazilian government's new regulatory sanitation framework [3] was approved in December 2019, establishing goals to accelerate water and sewerage coverage, stimulating private investors either to build new or to operate existing plants. However, the asset inventory handover process from the public to the private sector is unstructured, causing numerous operational and maintenance challenges to new operators and investors. This paper presents the digital transformation framework applied in Aegea, a private group of water and sewage utilities in Brazil, aiming to meet in a sustainable way a social, environmental and financial value (SLO - Social License to Operate) [15] by combining Building Information Modelling (BIM) [17] and Asset Management (AM) [8] disciplines. Aegea's integrated approach, "Infra Inteligente" (Infra), introduces intelligent 3D models of Water and Sanitation business. The 3D business representations trigger the Digital Twin in unrivaled data and analytics visualization within a virtual reality environment supporting the organization to take strategic and tactical decisions to do the maintenance and operations of the inherited plants. By switching from reactive to proactive maintenance it will save millions of Brazilian Reais, extending the life of critical system assets and prevent the operation team from dealing with frequent and unpredictable equipment breakdowns. © 2021, The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG.	This paper presents the digital transformation framework applied in Aegea, a private group of water and sewage utilities in Brazil, aiming to meet in a sustainable way a social, environmental and financial value (SLO - Social License to Operate) [15] by combining Building Information Modelling (BIM) [17] and Asset Management (AM) [8] disciplines.	By switching from reactive to proactive maintenance it will save millions of Brazilian Reais, extending the life of critical system assets and prevent the operation team from dealing with frequent and unpredictable equipment breakdowns.	AM, BIM, Digital Twin, SLO	Architectural design, Data visualization, Digital twin, Sanitation, Maintenance, Privatization, Sewage, Sewers, Sustainable development, Three dimensional computer graphics, Virtual reality, Building Information Modelling, Digital transformation, Infrastructure assets, Maintenance and operation, Proactive maintenance, Social and environmental, Virtual-reality environment, Water and wastewater, Water treatment	Management	BIM
Ceccon L.	2021	Springer Tracts in Civil Engineering		10.1007/978-3-030-49278-6_12	AI-BIM Interdisciplinary Spill-Overs: Prospected Interplay of AI and BIM Development Paradigms	BIM and AI—along with other cutting-edge technologies – are converging towards a data-rich, sematic approach to modelling and design. We analyse some of the current uses of AI in combination with BIM technology, as well as some very recent approaches which may disrupt the paradigms in use within the AEC field. The most promising features suggest a huge potential for liberating the designers from the most repetitive tasks and even endow them with a whole baggage of best practices, as dynamically emerging from the available data stored in BIM models and elaborated by AI. However, in order to achieve this, some issues must be dealt with, especially as regards the knowledge-sharing framework. Furthermore, the potentialities of AI in the field of architecture poses questions about the function, goals and ultimately the role of (human) designers in the world of AI-aesthetics and practice. © 2021, The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG.	We analyse some of the current uses of AI in combination with BIM technology, as well as some very recent approaches which may disrupt the paradigms in use within the AEC field.	The potentialities of AI in the field of architecture poses questions about the function, goals and ultimately the role of (human) designers in the world of AI-aesthetics and practice.	AI, BIM			Analysis	BIM
Jewett B.	2021	Lecture Notes in Civil Engineering		10.1007/978-3-030-51295-8_70	Field BIM: Establishing a Requirements Framework for Mobile BIM Technologies	Field BIM and its enabling Mobile BIM Technologies (MBT) are increasingly recognised for their role in improving collaboration and integration between project teams on construction sites. Very limited research about the development and applications of Field BIM and MBT is available in the literature. The few available studies have generally focused on specific types of MBT and their application on a single project or individual use cases. A framework to clarify the technical and business requirements of MBT is still missing. This paper is part of a wider research aiming to develop a holistic framework for MBT and Field BIM consisting of a requirements taxonomy, a benefits evaluation approach linking use cases to relevant performance metrics, and a project and supply chain performance analytics dashboard. This paper presents the findings about the technical and business requirements of MBT, which represents the first step towards the development of the requirements taxonomy. © 2021, The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG.	This paper is part of a wider research aiming to develop a holistic framework for MBT and Field BIM consisting of a requirements taxonomy, a benefits evaluation approach linking use cases to relevant performance metrics, and a project and supply chain performance analytics dashboard.	This paper presents the findings about the technical and business requirements of MBT, which represents the first step towards the development of the requirements taxonomy.	BIM, Field BIM, Mobile BIM technology	Supply chains, Taxonomies, BIM technologies, Business requirement, Evaluation approach, Construction sites, Development and applications, Holistic frameworks, Performance metrics, Supply chain performance, Architectural design	Design	BIM
Li S.-T.	2020	IEEE International Conference on Industrial Engineering and Engineering Management		10.1109/IEEM45057.2020.9309743	An application on building information model to procurement strategy of copper raw material with big data analytics	This research uses big data analysis to find the key factors of copper futures price fluctuations, successfully predicts copper price fluctuations, and applies them to the purchase strategy of copper raw materials for plant construction to help reduce plant construction costs. Since copper is an indispensable raw material in all building structures and pipeline configuration, the control of price will help manufacturers from all walks of life to control the fluctuations in the price of copper raw materials and reduce the cost of building plants in the early stage of plant construction. Manufacturers ,win at the starting point. © 2020 IEEE.	This research uses big data analysis to find the key factors of copper futures price fluctuations, successfully predicts copper price fluctuations, and applies them to the purchase strategy of copper raw materials for plant construction to help reduce plant construction costs.	the control of prices will help manufacturers from all walks of life to control the fluctuations in the price of copper raw materials and reduce the cost of building plants in the early stage of plant construction.	Big Data Analysis, Building Information Modeling (BIM), Copper Price, Enterprise Resource Planning (ERP), Work Breakdown Structure (WBS)	Big data, Cost benefit analysis, Manufacture, Cost reduction, Data Analytics, Building information Model - BIM, Building structure, Copper prices, Pipeline configuration, Plant construction, Price fluctuation, Procurement strategy, Advanced Analytics	Analysis	BIM
Cherkina V.	2020	E3S Web of Conferences		10.1051/e3sconf/202021503007	The role of information modeling and automated technologies in the design and construction of high-rise buildings	The purpose of the work is to consider the role of information modeling and automated technologies in the design and construction of high - rise buildings. The introduction of digital information tools in the construction sector provides rich ground for the birth and growth of companies specializing in the application of technology in design and construction. While some of the technologies are new, many companies implement ideas proposed in building research several decades ago that were impractical without a reliable digital database of building information. High-rise building information modeling (BIM) itself dates back to a landmark 1975 paper	The purpose of the work is to consider the role of information modeling and automated technologies in the design and construction of high - rise buildings.	While some of the technologies are new, many companies implement ideas proposed in building research several decades ago that were impractical without a reliable digital database of building information. High-rise building information modeling (BIM) itself dates back to a landmark 1975 paper	Artificial intelligence, Biotechnology, Construction, Construction industry, Information theory, End effectors, Food technology, Investments, Tall buildings, Automated technology, Construction sectors, Construction technologies, Design and construction, Design and planning, Digital		Design	AI

KASUYA T.	2020	AIJ Journal of Technology and Design		10.3130/aij|26.1246	Research on data model generation of bacs using bim and data analysis method	With the spread of AI and IoT, BACS (Building Automation and Control Systems) has also become more sophisticated. Although many of these systems are cloud-based, the lack of metadata in data collected from local BACS creates problems such as inconsistency with local devices and difficulty in cross-cutting data analysis. In this paper, we propose metadata assignment and information model generation methods for cloud-based BACS using BIM and data analysis. We developed and evaluated a tool to automate the extraction of spatial structure and to infer the suitable class of a point of BACS by data analysis. © 2020 Architectural Institute of Japan. All rights reserved.	In this paper, we propose metadata assignment and information model generation methods for cloud-based BACS using BIM and data analysis.	We developed and evaluated a tool to automate the extraction of spatial structure and to infer the suitable class of a point of BACS by data analysis.	BACS, BIM, Data analysis, IoT, Metadata	Architectural design, Information analysis, Building automation and control systems, Intelligent buildings, Metadata, Cloud-based, Cross-cutting, Data analysis methods, Information Modeling, Model generation, Spatial structure, Data handling	Design	BIM
Gou H.	2020	Tumu yu Huanjing Gongcheng Xuebao/Journal of Civil and Environmental Engineering		10.11835/j.issn.2096-6717.2020.103	State-of-the-art review of bridge informatization and intelligent bridge in 2019	With the global trend of informationization and intelligence in development of scientific and technological innovation, bridge engineering faces new opportunities for innovation. There is a trend of developing intelligent and high-precision bridges, which may profoundly transform the whole life cycle of bridge design, construction and maintenance. To reveal the progress and trend in this field, this paper reviews related research worldwide in 2019, with regard to bridge informatization, intelligent inspection, high-performance intelligent materials, and intelligent disaster prevention/mitigation, and proposes prospects of future research opportunities. According to the review, BIM technologies can significantly improve the productivity, performance, and integration of construction, maintenance and management of bridges. With the development of 5G technology, digital twinning has been introduced into the field of bridge management and maintenance. Intelligent inspection technologies (e. g. UAV and robots) and intelligent algorithms (e. g. computer vision, big data, and deep learning) continuously enrich bridge monitoring methods and improve the accuracy and efficiency. Development and applications of high-performance intelligent construction materials have provided strong thrusts to the development of intelligent bridges. Development of artificial intelligence (AI) technologies bring new approaches for disaster prevention of structures and transportation. To support national development strategies and ensure safety and durability of bridges, future research should focus on the theme of .bridge informatization and intelligence to carry out theoretical innovation, technical research and engineering applications. © 2020, Editorial Department of JCEE. All right reserved.	There is a trend of developing intelligent and high-precision bridges, which may profoundly transform the whole life cycle of bridge design, construction and maintenance. To reveal the progress and trend in this field, this paper reviews related research worldwide in 2019, with regard to bridge informatization, intelligent inspection, high-performance intelligent materials, and intelligent disaster prevention/mitigation, and proposes prospects of future research opportunities. According to the review, BIM technologies can significantly improve the productivity, performance, and integration of construction, maintenance and management of bridges	To support national development strategies and ensure safety and durability of bridges, future research should focus on the theme of .bridge informatization and intelligence to carry out theoretical innovation, technical research and engineering applications. According to the review, BIM technologies can significantly improve the productivity, performance, and integration of construction, maintenance and management of bridges.	Artificial intelligence (AI), Bridge informatization, Building information model (BIM), Deep learning, Intelligent detection		Management	AI
Duan X.	2020	Journal of Railway Engineering Society			Research on the 3D Nonlinear Intelligent Control for Bridge Engineering Operation and Maintenance Cost	Research purposes: Taking Zhangjiachuang bridge as an example, this paper makes an empirical study on the 3D nonlinear intelligent control of bridge operation and maintenance cost, and applies the 3D nonlinear intelligent control technology to the actual project to improve the timeliness and efficiency of operation and maintenance management, and effectively control the operation and maintenance cost. Research conclusions: (1) On the basis of collecting safety data of similar projects, this paper uses artificial intelligence methods such as particle swarm optimization algorithm and BP neural network to establish the operation and maintenance cost prediction model of Zhangjiachuang bridge. The model can accurately predict the operation and maintenance cost of the target project by inputting the characteristic value of the target project. (2) PDCA, EVM, BIM and other management theories and methods are used to strengthen the visual control of the whole process of bridge operation and maintenance. Through the actual data, the effect of operation and maintenance management is verified, the operation and maintenance cost is reduced. (3) In this paper, the 3D nonlinear intelligent control model can provide reference for the operation and maintenance cost control of bridge engineering. © 2020, Editorial Department of Journal of Railway Engineering Society. All right reserved.	On the basis of collecting safety data of similar projects, this paper uses artificial intelligence methods such as particle swarm optimization algorithm and BP neural network to establish the operation and maintenance cost prediction model of Zhangjiachuang bridge.	In this paper, the 3D nonlinear intelligent control model can provide reference for the operation and maintenance cost control of bridge engineering.	Bridge engineering, Cost management, Intelligent optimization, Operation and maintenance	Backpropagation, Cost engineering, Intelligent control, Predictive analytics, Maintenance, Particle swarm optimization (PSO), Railroad bridges, Artificial intelligence methods, BP neural networks, Bridge engineering, Characteristic value, Effect of operations, Empirical studies, Operation and maintenance, Particle swarm optimization algorithm, Costs	Management	AI
Hegemann F.	2020	Geomechanik und Tunnelbau		10.1002/geot.202000034	Digitalisation and IoT in mechanised tunnelling – an integral approach [Digitalisierung und IoT im maschinellen Tunnelbau – Ein integraler Ansatz]	The article presents a platform approach, in which the almost complete linking of machine data analysis, Building Information Modelling, document management system and digital ground models can be carried out in real time during a mechanised tunnel drive. All processes of mechanised tunnelling are digitalised and further processed in various applications in real time. The subsequent examples should demonstrate that there are now practically no application limits to the digitalisation of tunnel construction sites. Furthermore the potential and limits of artificial intelligence and machine learning are presented. © 2020, Ernst und Sohn. All rights reserved.	The article presents a platform approach, in which the almost complete linking of machine data analysis, Building Information Modelling, document management system and digital ground models can be carried out in real time during a mechanised tunnel drive.	The subsequent examples should demonstrate that there are now practically no application limits to the digitalisation of tunnel construction sites. Furthermore the potential and limits of artificial intelligence and machine learning are presented.	AI, BIM, Data management platform, General, Mechanised tunnelling, Process controlling	Artificial intelligence, Information services, Digital storage, Information management, Application limit, Building Information Modelling, Document management systems, Ground models, Integral approach, Platform approach, Real time, Tunnel construction, Internet of things	Management	AI
Igwe U.S.	2020	IOP Conference Series: Materials Science and Engineering		10.1088/1757-899X/884/1/012041	Recent Technologies in Construction A Novel Search for Total Cost Management of Construction Projects	There is a continuous rise in the implementation of information-driven technology in construction, especially for effective control and management of construction resources. However, the enormous opportunities that these technologies provide have not been adequately utilized for construction cost management. There are so many innovations in the current IR 4.0 era, where digitization and connected systems are the trend of activities in engineering and other allied industries. These innovations are being adopted in the construction industry, to enhance the efficiency of construction processes. The areas of the current trend include Internet of things [IoT], Augmented and Virtual Reality [AR and VR], SD-BIM, Autonomous Equipment, Artificial Intelligence and Machine Learning, and Predictive Analytics. This paper explores the applications and benefits of these areas of new technological trends in construction project management with emphasis laid in cost management of construction projects. Eighty-one[81] recent publications in journal articles, textbooks, web pages and conference proceedings published between 2008 and 2019 were reviewed in order to articulate and reveal areas of application of the technologies in project cost management and control. The paper exposes areas of application of the current ICT trends which construction managers and project cost managers should harness. © Published under licence by IOP Publishing Ltd.",	This paper explores the applications and benefits of these areas of new technological trends in construction project management with emphasis laid in cost management of construction projects.	The paper exposes areas of application of the current ICT trends which construction managers and project cost managers should harness.			Management	AI
Sinak N.	2020	IOP Conference Series: Materials Science and Engineering		10.1088/1757-899X/869/6/062041	The impact of proptech on real estate industry growth	The real estate industry is currently undergoing a digital transformation that not only changes its nature in terms of the markets and work environments, but is also influencing its growth. What are the main trends and concerns related to this transformation? To what extent is the real estate industry already prepared for this? This paper reviews the situation in terms of the emergence of a phenomenon known as PropTech. PropTech is characterized by the massive implementation of emerging technology such as home matching tools, drones, virtual reality, building information modelling (BIM), data analytics tools, artificial intelligence (AI), Internet of Things (IoT) and blockchain, smart contracts, crowdfunding in the real estate sector, fintechs related to real estate, smart cities, regions, smart homes and shared economy. This survey of changes in the real estate industry due to PropTech covers four areas: (1) PropTech applications in the real estate industry, (2) implications of PropTech for real estate market transparency (3) how PropTech could give a region or a company a competitive advantage and (4) concerns on the wider implications of these changes on a labour market and education. In a plausible scenario, changing the real estate technologies could change system dynamics and improve real estate market transparency. Moreover, it can be asserted that, in a broader sense, PropTech is beneficial for territorial competition and territorial growth strategies. And lastly, under different institutional arrangements, PropTech can affect the changing structure of the real estate market, the demand for hi-tech, new skills as well as emerging policy challenges for the real estate industry. © 2020 Published under licence by IOP Publishing Ltd.",	This paper reviews the situation in terms of the emergence of a phenomenon known as PropTech. PropTech is characterized by the massive implementation of emerging technology such as home matching tools, drones, virtual reality, building information modelling (BIM), data analytics tools, artificial intelligence (AI), Internet of Things (IoT) and blockchain, smart contracts, crowdfunding in the real estate sector, fintechs related to real estate, smart cities, regions, smart homes and shared economy.	And lastly, under different institutional arrangements, PropTech can affect the changing structure of the real estate market, the demand for hi-tech, new skills as well as emerging policy challenges for the real estate industry.			Analysis	BIM
Jianfeng Z.	2020	Proceedings - 2020 5th International Conference on Smart Grid and Electrical Automation, ICSGEA 2020		10.1109/ICSGEA51094.2020.00066	Construction of Intelligent Building Design System Based on BIM and AI	This paper analyzes the function of each subsystem under the overall framework of intelligent building, and puts forward an intelligent building design system based on BIM and artificial intelligence. The system is divided into data layer, model layer and application layer. It uses engineering feature modeling, engineering structure model decomposition, machine learning and other methods to establish a parametric construction project information management model. Then the function and application process of optimization control, dynamic construction management and dynamic construction simulation are optimized. According to the BIM system platform, the information interaction access rights of all participants in the project are determined. Finally, the scheme and implementation promotion strategy are applied to the specific pilot project. The results show that the system can directly reduce the workload and difficulty of intelligent design, and improve the design efficiency and quality. © 2020 IEEE.	This paper analyzes the function of each subsystem under the overall framework of intelligent building, and puts forward an intelligent building design system based on BIM and artificial intelligence.	The results show that the system can directly reduce the workload and difficulty of intelligent design, and improve the design efficiency and quality.	AI, big data, BIM, intelligent building, modeling	Artificial intelligence, Electric power transmission networks, Intelligent buildings, Engineering education, Information management, Project management, Smart power grids, Structural design, Application process, Construction projects, Dynamic construction, Engineering structures, Information interaction, Intelligent designs, Optimization control, Promotion strategies, Architectural design	Design	BIM
Doherty M.	2020	IEEE IAS Electrical Safety Workshop		10.1109/ESW42757.2020.9188324	Application of artificial intelligence in electrical safety	As artificial intelligence (AI) becomes more sophisticated in imitating human cognitive processes (e.g., problem solving, object detection, and learning), it has transformed several industry sectors and has had a growing impact on the way construction projects are delivered. One of the areas that has great potential to advance breakthroughs for innovative improvements is in electrical safety. Data generated from images captured from mobile devices, unmanned aerial vehicles, wearable sensors, building information modeling (BIM), and others present an opportunity for construction safety professionals and in many other sectors to analyze and benefit from the insights generated from the data using AI, machine learning and deep learning systems. For example, AI-based algorithms can be used to scan images from jobsites for safety hazards, such as workers not wearing protective equipment, and correlate the images with accident records, identify unsafe worker behavior and suggest training and education priorities or track the real-time interactions of workers, machinery, and objects on the site and alert supervisors of potential safety issues. Using AI to execute the existing Shock and Arc Flash Risk Assessment Procedure templates from CSA Z462 and NFPA 70E as real-world scenarios and the potential ethical factors from the workers perspectives will also be discussed. Considering AI's immense potential, this study aims to synthesize emerging trends of artificial intelligence in electrical safety. © 2020 IEEE.	Using AI to execute the existing Shock and Arc Flash Risk Assessment Procedure templates from CSA Z462 and NFPA 70E as real-world scenarios and the potential ethical factors from the workers perspectives will also be discussed. Data generated from images captured from mobile devices, unmanned aerial vehicles, wearable sensors, building information modeling (BIM), and others present an opportunity for construction safety professionals and in many other sectors to analyze and benefit from the insights generated from the data using AI, machine learning and deep learning systems.	Considering AI's immense potential, this study aims to synthesize emerging trends of artificial intelligence in electrical safety.	Artificial Intelligence (AI), Data Mining, Machine Learning	Architectural design, Deep learning, Object detection, Learning systems, Machinery, Personnel training, Problem solving, Risk assessment, Risk perception, Safety engineering, Wearable antennas, Accident prevention, Building Information Model - BIM, Construction projects, Construction safety, Protective equipment, Real time interactions, Real-world scenario, Training and education, Occupational risks	Design	BIM
Grobelny L.	2020	IABSE Symposium, Wroclaw 2020: Synergy of Culture and Civil Engineering - History and Challenges, Report			BIM basic workflows in bridge design-challenges and difficulties	The paper deals with the issue of implementation of BIM technology in the bridge design process. Bridges are very important structures which were designed and built without advanced analytical tools and computer programs to operate for hundreds of years. Demand for the high reliability of bridge structures resulted in the development of special analytical techniques. On one hand, ensuring the safety of a bridge is a superior task. On the other hand, almost every bridge is composed of a regular main structural system and many structural elements with local importance in overall analysis, which allows of universal automated solutions. First, the paper presents the traditional approach which is based on well-known and easily accessible 2D documentation for creating complex structural systems. The approach is easy to apply in the case of the simplest bridges, as well as the extradosed bridges. Next, a modern solution, generally called ,the 3D parametrized modelling, is analysed in terms of its advantages and disadvantages in design of bridges. The level of geometrical and analytical detail (LoD), the level of information (LoI), as well as the time effort or cost limitations were analysed. As a result, basic workflows which include all the important connections between various elements of the process are presented and compared. © 2020 IABSE Symposium, Wroclaw 2020: Synergy of Culture and Civil Engineering - History and Challenges, Report. All rights reserved.	The paper deals with the issue of implementation of BIM technology in the bridge design process.	As a result, basic workflows which include all the important connections between various elements of the process are presented and compared.	Bim, Bridge, Building information modelling, Design, Dynamo, Revit, Architectural design, Softstik	3D modeling, Advanced Analytics, History, Automated solutions, BIM technologies, Bridge structures, Extradosed bridge, High reliability, Structural elements, Structural systems, Traditional approaches, Bridges	Design	BIM
Krupik P.	2020	International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM		10.5593/sgem2020/5.2/s21.084	Construction 4.0 with a focus on transport construction	Digital and technological innovations that have grown rapidly in recent years have been referred to as the 4th Industrial Revolution or Industry 4.0. The fourth industrial revolution as a whole will decisively reshape all phases of the process of investment preparation, their implementation and the subsequent administration and maintenance of buildings. These changes will fundamentally affect most construction professions and will require changes in their knowledge and skills. Some professions will disappear, some will be newly constituted, which will require a new constitution of lifelong learning systems. Ensuring the competitiveness of the Czech Republic and the Czech construction industry will require purposeful monitoring of these trends, support for research and innovation, support for start-ups and support for small and medium-sized enterprises in particular and their approaches to these innovations. It seems as if the construction industry is somewhat aside. The big topic in present construction is BIM (Building Information Modeling), but this is just one component of the considered Construction 4.0. Other topics, if not completely neglected, are minimally delayed. Nevertheless, it is important to deal with them. These include virtual and augmented reality, 3D printers, advanced building materials, prefabricated and modular designs, Big data and predictive analytics, 3D scanning and photogrammetry, autonomous vehicles and drones, cloud collaboration (real-time collaboration) or wireless monitoring and connecting equipment. The paper comprehensively deals with the description of the Construction 4.0 with a focus on the environment of the Czech Republic and on transport construction. The content is complemented by an assessment of the current situation, indicating the possibility of use in practice. © 2020 International Multidisciplinary Scientific GeoConference. All rights reserved.	The paper comprehensively deals with the description of the Construction 4.0 with a focus on the environment of the Czech Republic and on transport construction.	The content is complemented by an assessment of the current situation, indicating the possibility of use in practice.	Construction 4.0, Construction industry, Industry 4.0, Transport construction	3D printers, Augmented reality, Competition, Learning systems, Construction industry, Industry 4.0, Maps, Photogrammetry, Predictive analytics, Remote sensing, Surveying, Advanced building materials, Building Information Model - BIM, Industrial revolutions, Real-time collaboration, Small and medium sized enterprise, Technological innovation, Virtual and augmented reality, Wireless monitoring, Architectural design	Design	AI

Gao X.	2020	Construction Research Congress 2020: Computer Applications - Selected Papers from the Construction Research Congress 2020			Machine Learning-Based Building Life-Cycle Cost Prediction: A Framework and Ontology	Numerous costs are associated with the design, construction, installation, operation, maintenance, and deconstruction of a building or building system. One of the challenges usually faced by an organization's capital planning department and/or facility management department is that they do not have an effective means to quickly estimate a new facility's whole life-cycle costs (LCC) during the programming phase when no building design is available. To provide facility managers and owners with an effective and reliable means to assess the total cost of the facility ownership, the authors are developing an approach that uses the historical data stored in multiple building systems and building information models (BIM) as basis to predict facilities' LCC - initial design and construction cost, utility cost, and operation and maintenance cost. In this paper, the authors propose a machine learning-enabled facility LCC analysis framework using data provided by building systems. The corresponding domain ontology - LCCA-Onto - is also presented. The proposed approach provides organizations who own multiple facilities with an innovative solution to the LCC prediction issue. © 2020 American Society of Civil Engineers.	In this paper, the authors propose a machine learning-enabled facility LCC analysis framework using data provided by building systems.	The proposed approach provides organizations who own multiple facilities with an innovative solution to the LCC prediction issue.	Construction, Cost benefit analysis, Costs, Forecasting, Life cycle, Machine learning, Predictive analytics, Office buildings, Ontology, Turing machines, Analysis frameworks, Building Information Model - BIM, Building life cycle, Facility management, Innovative solutions, Multiple buildings, Multiple facilities, Operation and maintenance, Architectural design		Management	AI
Ghannoum C.	2020	Construction Research Congress 2020: Project Management and Controls, Materials, and Contracts - Selected Papers from the Construction Research Congress 2020			Revisiting the Roles of Structural Engineering Design Professionals under Their Increasing Risks and Associated Liabilities	Structural engineering is an age-long profession which historically has played a central role in shaping our landscapes and societies with countless iconic structures. However, throughout the years, the role of structural engineers has significantly changed. From the „master builder, responsible for all project aspects, their role nowadays is often confined to ensuring structural integrity. They are considered as supporting members led by others and are seldom involved in project decision-making. The paper aims at addressing the marginalized role of structural engineers which currently is not aligned with the vital importance of their profession. The methodology adopted consisted of a literature review to explore two main aspects. First, the role and competencies of structural engineers were investigated with respect to established and emerging fields such as structural and construction safety, integrated design, new project delivery methods, sustainable design, BIM, and other technological developments, including artificial intelligence and data analytics. Second, the new increased responsibilities, challenges, and liabilities that structural engineers are subjected to were identified. The findings revealed that in most fields, structural engineers play secondary roles especially as compared to architects. Unrealistic requirements and deadlines are frequently imposed on them and they operate in a legal context that does not properly shield them from professional liabilities. This is often hindering their performance as they become more conservative and averse to risk to the detriment of innovation and value engineering. Structural engineers should be proactive in redefining a more prominent and wider role for themselves. They should also regain control of decisions that directly affect their work. This will help their profession reach new heights while mitigating their risks and liabilities. © 2020 American Society of Civil Engineers.	The paper aims at addressing the marginalized role of structural engineers which currently is not aligned with the vital importance of their profession.	The findings revealed that in most fields, structural engineers play secondary roles especially as compared to architects.	Advanced Analytics, Architectural design, Artificial intelligence, Data Analytics, Decision making, Engineers, Sustainable development, Professional aspects, Structural design, Value engineering, Construction safety, Engineering design, Integrated designs, Literature reviews, Professional liability, Project decision, Structural engineer, Technological development, Project management		Design	Analytics
Meng L.L.	2020	RE: Anthropocene, Design in the Age of Humans - Proceedings of the 25th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2020			T-SNE: A Dimensionality Reduction Tool for Design Data Visualisation	One can argue that data is the 'new oil'. Yet more important than the sheer quantity of data is the question, in the context of architecture and design, how data is represented in design, as this is becoming a more relevant question to the architectural profession. We argue that data, in particular n-dimensional, is often hidden even in BIM models. Hence we propose a new way of understanding the space by (1) generate and integrate space analytics data using space syntax method as well as space usage data and (2) visualise the data using t-Distributed Stochastic Neighbour Embedding (t-SNE), an unsupervised learning and dimensionality reduction tool to help intuitively display high dimensions of data. This approach may help to discover the 'hidden layers' of the building information that may be otherwise omitted. This investigation, its proposed hypothesis, methodology, implications, significance and evaluation are presented in the paper. © 2020 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.	Hence we propose a new way of understanding the space by (1) generate and integrate space analytics data using space syntax method as well as space usage data and (2) visualise the data using t-Distributed Stochastic Neighbour Embedding (t-SNE), an unsupervised learning and dimensionality reduction tool to help intuitively display high dimensions of data.	This approach may help to discover the 'hidden layers' of the building information that may be otherwise omitted. This investigation, its proposed hypothesis, methodology, implications, significance and evaluation are presented in the paper. © 2020 and published by the Association for Computer-Aided Architectural Design Research in Asia	Data-driven design, Machine learning, Space syntax, T-sne	Data visualization, Dimensionality reduction, Stochastic systems, Design data, Architecture professions, Bim models, Hidden layers, High dimensions, Space syntax, Space usage, Architectural design	Design	Analytics
Tan T.	2020	EG-ICE 2020 Workshop on Intelligent Computing in Engineering, Proceedings			BIM-enabled design for manufacture and assembly	Design for Manufacture and Assembly (DfMA) has been introduced into the construction industry to enhance production efficiency. DfMA is a design approach and evaluation system for improving manufacturability and assemblability. This paper outlines the past and ongoing Artificial Intelligence (AI) development in manufacturing-oriented DfMA, and provides a literature review of the concept and the use of DfMA in the construction. The applications, challenges and barriers of design optimization through DfMA and BIM-enabled DfMA are summarized. This desk study shows that studies related to construction-oriented DfMA are still in infancy. At present, articles about DfMA are focused on optimizing design and engineering for manufacturability and assemblability, but rarely describe its digital enablement. This study makes up for the lack of literature review in the evaluation of DfMA with concluding a preliminary application framework, and proposes a future-oriented study and new direction for BIM-enabled DfMA. © EG-ICE 2020 Workshop on Intelligent Computing in Engineering, Proceedings. All rights reserved.	This paper outlines the past and ongoing Artificial Intelligence (AI) development in manufacturing-oriented DfMA, and provides a literature review of the concept and the use of DfMA in the construction.	This study makes up for the lack of literature review in the evaluation of DfMA with concluding a preliminary application framework, and proposes a future-oriented study and new direction for BIM-enabled DfMA.	Architectural design, Construction industry, Intelligent computing, Machine design, Manufacture, Application frameworks, Design optimization, Design approaches, Design for manufacture and assemblies, Literature reviews, Manufacturability, Optimizing design, Production efficiency, Design for manufacturability		Design	BIM
Yang S.	2020	International Journal of Engineering Business Management		10.1177/18479790120448749	Ambidextrous learning of engineering project team: Relying on control or BIM As VR AR MR?	Through formal control and social control, technology platforms can acquire the information knowledge needed for ambidextrous learning of engineering project team, but whether technology platforms influence ambidextrous learning of engineering project team through the intermediary role of ambidextrous control (formal control, social control) is still lack of theoretical and empirical support. In order to explore the influence of the co-use of technology platform and ambidextrous control on the ambidextrous learning of engineering project team, this paper constructs a theoretical framework between the performance of ambidextrous control (formal control, social control) and different types of technology platform (BIM, AI, VR, AR, MR) and different types of learning (exploratory learning, exploitative learning). A questionnaire survey was conducted among 210 project managers. AMOS22.0 and bootstrap software were used for analysis and test, SPSS22.0 was used for hierarchical regression analysis, the results of hierarchical regression analysis show that formal control, social control and the balanced use of both have significant positive correlation with the ambidextrous learning and balanced use of ambidextrous learning of engineering project team. Formal information Technology Platform (BIM) and informal information Technology Platform (AI, VR, AR, MR) have significant positive effects on the ambidextrous learning of engineering project team. The balanced use of formal information Technology Platform (BIM) and informal information Technology Platform (AI, AR) has significant positive effects on the ambidextrous learning balance of engineering project team. Formal control and social control mediate the positive correlation between information technology platform (BIM, AI, VR, AR, MR) and ambidextrous learning of engineering project team. In addition, information technology platform (BIM, AI, VR) regulates the impact of formal control and social control on learning (exploratory learning, exploitative learning). Generally speaking, different types of technology platforms and ambidextrous control strategies are still effective for the ambidextrous learning and balance of engineering project team. © The Author(s) 2020.	This paper constructs a theoretical framework between the performance of ambidextrous control (formal control, social control) and different types of technology platform (BIM, AI, VR, AR, MR) and different types of learning (exploratory learning, exploitative learning).	Generally speaking, different types of technology platforms and ambidextrous control strategies are still effective for the ambidextrous learning and balance of engineering project team.	AI, ambidextrous learning, AR, BIM, Control		Analysis	BIM
Zhang H.	2020	Proceedings - 2020 International Conference on Intelligent Transportation, Big Data and Smart City, ICITBS 2020		10.1109/ICITBS49701.2020.00167	Intelligent building planning system based on bim and artificial intelligence	In order to solve the problems encountered in the construction industry and improve the competitiveness of the construction industry in the world, BIM technology has emerged. BIM technology brings the construction industry into the field of information technology. Therefore, this paper aims to establish a scientific and practical project performance evaluation system for construction companies based on the use of BIM technology in the construction phase to measure and evaluate the changes in the project management, economic efficiency, and other aspects of BIM technology used by construction companies. Based on the methods of function modeling, data modeling and process modeling, BIM evolutionary model and digital integrated delivery process are established. Different data sources are integrated and classified by classification and coding system, and the BIM model of operation and maintenance is obtained through data reorganization and optimization of the model. Operation and maintenance BIM model can be better compatible with facility management information system and improve the efficiency and efficiency of operation and maintenance management. © 2020 IEEE.	Therefore, this paper aims to establish a scientific and practical project performance evaluation system for construction companies based on the use of BIM technology in the construction phase to measure and evaluate the changes in the project management, economic efficiency, and other aspects of BIM technology used by construction companies.	Operation and maintenance BIM model can be better compatible with facility management information system and improve the efficiency and efficiency of operation and maintenance management.	AI, Big data, Bim, Building planning system, Data mining	Architectural design, Big data, Efficiency, Competition, Construction industry, Information management, Intelligent buildings, Maintenance, Office buildings, Smart city, Classification and coding systems, Construction companies, Data reorganization, Economic efficiency, Evolutionary models, Facility management, Operation and maintenance, Practical projects, Project management	Management	AI
Dalal S.	2020	IIBM Journal of Research and Development		10.1147/JRD.2019.2945693	Deep analytics for workplace risk and disaster management	We discuss dynamic real-time analysis from multimodal data fusion for contextual risk identification to generate 'risk maps' for the workplace, resulting in timely identification of hazards and associated risk mitigation. It includes new machine/deep learning, analytics, methods, and its applications that deal with the unconventional data collected from pictures, videos, documents, mobile apps, sensors/Internet of Things, Occupational Safety and Health Administration (OSHA) rules, and Building Information Model (BIM) Models. Specifically, we describe a number of advances and challenges in this field with applications of computer vision, natural language processing, and sensor data analysis. Applications include automated cause identification, damage prevention, and disaster recovery using current and historical claims data and other public data. The methods developed can be applied to any given situation with different groups of people, including first responders. Finally, we discuss some of the important nontechnical challenges related to business practicality, privacy, and industry regulations. © 1957-2012 IBM.	We discuss dynamic real-time analysis from multimodal data fusion for contextual risk identification to generate 'risk maps' for the workplace, resulting in timely identification of hazards and associated risk mitigation.	Specifically, we describe a number of advances and challenges in this field with applications of computer vision, natural language processing, and sensor data analysis. Applications include automated cause identification, damage prevention, and disaster recovery using current and historical claims data and other public data.	Architectural design, Damage detection, Data fusion, Disaster prevention, Disasters, Maps, Building Information Model - BIM, Natural language processing systems, Risk assessment, Disaster management, Industry regulations, Multimodal data fusion, NAtural language processing, Occupational safety and health administrations, Sensor data analysis, Timely identification, Occupational risks		Management	Analytics
Zhang H.	2020	Advances in Intelligent Systems and Computing		10.1007/978-981-15-2568-1_141	Comprehensive information management analysis of construction project based on BIM	Informatization management of construction projects refers to the application of information technology in various stages of the project construction process based on Computer technology, Internet technology, Internet of Things technology and Communication technology. Collect, store, and process information from different parties, and control various aspects such as project cost, schedule, quality, and safety to improve management efficiency and level. Apply building information models to construction projects and combine construction projects with modern information technology to realize the information management of all participants, the whole goal, the whole factor and the whole life cycle of the construction project. Exploring the path and method of realizing comprehensive informationization of construction projects from three aspects: combining modern information technology, Digital Twin and BIM-based collaboration. The realization of comprehensive information management of BIM-based construction projects is of great significance for better promoting the application of BIM and promoting the development of intelligent buildings and information management of construction projects in China. © Springer Nature Singapore Pte Ltd. 2020.	Apply building information models to construction projects and combine construction projects with modern information technology to realize the information management of all participants, the whole goal, the whole factor and the whole life cycle of the construction project. Exploring the path and method of realizing comprehensive informationization of construction projects from three aspects: combining modern information technology, Digital Twin and BIM-based collaboration.	The realization of comprehensive information management of BIM-based construction projects is of great significance for better promoting the application of BIM and promoting the development of intelligent buildings and information management of construction projects in China.	Building information modeling, Comprehensive information, Construction project management, Intelligent buildings	Advanced Analytics, Architectural design, Big data, Embedded systems, Construction, Digital twin, Information management, Information theory, Intelligent buildings, Life cycle, Quality control, Smart city, Application of information technologies, Building Information Model - BIM, Communication technologies, Comprehensive information, Construction project management, Construction projects, Internet of things technologies, Modern information technologies, Project management	Management	BIM
Sai Y.	2020	Advances in Intelligent Systems and Computing		10.1007/978-981-15-2568-1_74	Analysis of digital twins and application value of power engineering based on BIM	With the continuous advancement of computer and Internet technologies, the application of BIM technology in power engineering construction has also been widely developed. The paper proposes the integration of BIM technology and digital twinning technology to realize the informationization and intellectual construction of power engineering. Based on the BIM power engineering project management platform, the paper introduces digital twinning technology, and applies advanced methods such as Internet of Things and big data to give real-time dynamic information to the BIM model, and establishes power engineering digital twins approach from the perspective of the whole process and all participants. In addition, the application value of BIM technology and digital twin technology in power engineering is analyzed. Through the integration of BIM technology and digital twin technology, digital and intelligent management of power engineering construction can be realized, and real-time perception, resource sharing and application capabilities of smart building can be promoted. © Springer Nature Singapore Pte Ltd. 2020.	The paper proposes the integration of BIM technology and digital twinning technology to realize the informationization and intellectual construction of power engineering.	the paper introduces digital twinning technology, and applies advanced methods such as Internet of Things and big data to give real-time dynamic information to the BIM model, and establishes power engineering digital twins approach from the perspective of the whole process and all participants.	Comprehensive informationization, Digital twins, Project management, Smart building	Advanced Analytics, Architectural design, Big data, Project management, Embedded systems, Intelligent buildings, Smart city, Application capability, Informationization, Intelligent management, Internet technology, Power engineering, Real time perception, Real-time dynamics, Resource sharing, Digital twin	Management	BIM
Sabin J.	2020	Advances in Intelligent Systems and Computing		10.1007/978-3-030-29513-4_42	The functional design method for public buildings together with gamification of information models enables smart planning by crowdsourcing and simulation and learning of rescue environments	We have developed and piloted a method that can be used to create planning and learning environments that fuse buildings design with game programming. The method also allows e.g. to design and different simulations of building usage (like emergency evacuation by rescue teams). The method also brings together the students of game programming and buildings design with building users and construction professionals to work together towards mutual goals. This way they all learn in addition to group work to act in projects with students, building users and professionals of many disciplines. This is increasingly a key skill in the modern work life that relies heavily on projects. In this environment it is important for the actors to learn how to understand and appreciate the specialists of other disciplines and their professional skills. The gamified information model of a building can be used after its completion as a learning and testing space for the construction professionals. In the gamification we utilize our patented Functional Design Method for Buildings that enables to take into account the space needed for human actions in buildings or other targets under design in information model based (BIM) design of buildings. The objects to be dimensioned could e.g. be related to safety, loading and unloading areas or production processes and their requirements for space. An inverse approach is also possible. The method helps all actors of construction business, building users and students to better take into account and understand operational spatial requirements in a building and about safety. © Springer Nature Switzerland AG 2020.	We have developed and piloted a method that can be used to create planning and learning environments that fuse buildings design with game programming. The method also allows e.g. to design and different simulations of building usage (like emergency evacuation by rescue teams).	The method helps all actors of construction business, building users and students to better take into account and understand operational spatial requirements in a building and about safety.	AI, Barrier free, BIM, Crowdsourcing, Energy efficiency, Function dimensioning, Learning environment, Gamification, Learning, Multi-gaming, Simulation, Universal design	Artificial intelligence, Computer aided instruction, Construction, Construction industry, Crowdsourcing, Energy efficiency, Information theory, Intelligent systems, Inverse problems, Learning systems, Students, Unloading, Barrier-free	Design	BIM

Hu J.	2019	Proceedings - 2019 3rd International Conference on Data Science and Business Analytics, ICDSBA 2019		10.1109/ICDSBA48748.2019.00081	Automatic Checking of Substation Design Model with Visual Script of Design Codes	The design of a substation is a complex process with potential conflicts against design codes. The benefits of design collaboration based on Building Information Modeling (BIM) approach is still limited due to lack of timely feedback of conflicts between building components or electrical equipment modeled by different disciplines. If these conflicts can be automatically alerted for an in-progress design, unnecessary reworks can be prevented. However, the automatic checking of design model is frequently hindered by the difficulties of programming the design codes and reviewing programmed rules. In this regard, the study develops a framework of visual programming design codes, considering their usage for automatic checking design model defined by both the Industry Foundation Class (IFC) and the Grid Information Model (GIM). © 2019 IEEE.	The benefits of design collaboration based on Building Information Modeling (BIM) approach is still limited due to lack of timely feedback of conflicts between building components or electrical equipment modeled by different disciplines. If these conflicts can be automatically alerted for an in-progress design, unnecessary reworks can be prevented. However, the automatic checking of design model is frequently hindered by the difficulties of programming the design codes and reviewing programmed rule	In this regard, the study develops a framework of visual programming design codes, considering their usage for automatic checking design model defined by both the Industry Foundation Class (IFC) and the Grid Information Model (GIM).	Visual Programming, Automatic Checking, Building Information Modelling, Substation	Advanced Analytics, Computer programming, Information theory, Design collaboration, Building Information Model - BIM, Complex Processes, Electrical equipment, Industry Foundation Classes - IFC, Potential conflict, Substation design, Visual programming, Architectural design	Design	BIM
Raghavi V.	2019	2019 International Conference on Intelligent Computing and Control Systems, ICCS 2019		10.1109/ICCS45141.2019.9065840	AI based semantic extensibility and querying techniques for building information model	Building information model (BIM) is a new emergence in the field of Architecture, Engineering and Construction (AEC) industry, which facilitates detailed digital representation of a building. The BIM archetype describes the details of a building in the Industry Foundation Class (IFC), which is a platform-agnostic, open data model developed by buildingSMART. The BIM data model embeds interoperability and querying facility among its principal traits in support of the AEC industry. The building information is also required by domains outside the AEC industry, to develop a wide variety of applications such as smart building and indoor navigation systems. In such cases, the IFC data model falls short in supporting interaction with applications of external domains other than AEC. The proposed work is aimed to perform a study on various efforts undertaken in the integration of BIM model with external domain querying and reasoning systems, to retrieve details from underlying building models. © 2019 IEEE.	The proposed work is aimed to perform a study on various efforts undertaken in the integration of BIM model with external domain querying and reasoning systems	retrieve details from underlying building models.	Artificial Intelligence, Building Information Model, Industry Foundation Class, Interoperability, Ontology, Semantic Web	Control systems, Navigation systems, Information theory, Intelligent computing, Open Data, Semantics, , AEC Industry, Architecture , engineering and construction industries, Building Information Model - BIM, Building model, Digital representations, Indoor navigation system, Industry Foundation Classes - IFC, Reasoning system, Architectural design	Design	AI
Aljebory K.M.	2019	18th International Multi-Conference on Systems, Signals and Devices, SSD 2019		10.1109/SSD.2019.8893274	Developing AI Based Scheme for Project Planning by Expert Merging Revit and Primavera Software	Project control and monitoring tools are based on expert judgment and parametric tools. Some of these tools are Artificial Intelligence techniques. Today's project planning tools require the generation and sequencing of each activity. Establishing interactive computer based scheduled plan for a project requires not only injecting the information technology, but all project activities and inserting their durations and resource requirements in organized and sequenced manner. New parametric Building Information Modeling (BIM) software like Revit can dramatically enhance planning productivity by substantially reducing the work necessary for preparing construction schedule. The new parametric BIM can automate exchange of information during design, construction and service life of projects. In this paper, the Revit is connected to Primavera software by conducting expert system that supports automatic generation of the project plan scheduling scheme of project control functions. This will eliminate some of the most tedious and time consuming steps in creating a construction project schedule. © 2019 IEEE.	In this paper, the Revit is connected to Primavera software by conducting expert system that supports automatic generation of the project plan scheduling scheme of project control functions.	This will eliminate some of the most tedious and time consuming steps in creating a construction project schedule.	AI, BIM, Project Control, Project Planning	Artificial intelligence, Expert systems, Project management, Construction schedules, Artificial intelligence techniques, Construction projects, Exchange of information, Project control, Project planning, Project planning tool, Resource requirements, Architectural design	Management	BIM
Zhou P.	2019	Sustainable Civil Infrastructures		10.1007/978-3-030-01905-1_11	Text and Information Analytics for Fully Automated Energy Code Checking	Energy compliance checking aims to check the compliance of design information embedded in building information models (BIMs) with applicable building energy codes. To fully automate the compliance checking process – without the need to manually code the rules in a compliance checking software, there is a need to automatically process and understand the text in the codes, extract the relevant requirements from the text, and match the extracted requirements to the information in the BIMs. This is challenging because of the text complexities of the codes, including longer provisions, requirement exceptions, hierarchically-complex sentence structures, and different terminologies and levels of detail compared to BIMs. To address these challenges, a set of text and information analytics methods were proposed and implemented in an energy compliance checking prototype. The prototype includes four main modules: text classification, information extraction, semantic information alignment, and compliance checking and reporting. For testing the prototype, a BIM of an educational building was checked for compliance with three energy codes – the 2012 International Energy Conservation Code, the 2013 Building Energy Efficiency Standards (known as the California Energy Code), and the Ontario Building Code Supplementary Standard SB-10. A promising performance of 91.7% recall and 84.6% precision in noncompliance detection was achieved. This study could benefit different participants in the domain of architecture, engineering and construction, by streamlining the energy code compliance process in a fully-automated manner. Future research may test the proposed methods and prototype on other energy topics (e.g., fenestration) and different types of documents (e.g., contract specifications). The challenges for developing a compliance checking method that is fully-automated and generalized across different types of documents could also be studied. © 2019, Springer Nature Switzerland AG.	Energy compliance checking aims to check the compliance of design information embedded in building information models (BIMs) with applicable building energy codes. To fully automate the compliance checking process – without the need to manually code the rules in a compliance checking software, there is a need to automatically process and understand the text in the codes, extract the relevant requirements from the text, and match the extracted requirements to the information in the BIMs. This is challenging because of the text complexities of the codes, including longer provisions, requirement exceptions, hierarchically-complex sentence structures, and different terminologies and levels of detail compared to BIMs. To address these challenges, a set of text and information analytics methods were proposed and implemented in an energy compliance checking prototype. The prototype includes four main modules: text classification, information extraction, semantic information alignment, and compliance checking and reporting.	This study could benefit different participants in the domain of architecture, engineering and construction, by streamlining the energy code compliance process in a fully-automated manner.	Building Information Modeling (BIMs), Compliance Checking, Energy Code, Information Analysis Method, Non-compliance Detection	Architectural design, Automation, Energy efficiency, Building codes, Classification (of information), Energy policy, Historic preservation, Project management, Regulatory compliance, Semantics, Soil structure interactions, Text processing, Architecture , engineering and constructions, Building energy code, Building energy efficiency standards, Compliance checking, Contract specifications, Educational buildings, Semantic information, Text classification	Analysis	BIM
Nahangi M.	2019	Infrastructure Computer Vision		10.1016/B978-0-12-815503-5.00007-3	Use cases for subcontractors and fabricators	This chapter presents some opportunities that infrastructure computer vision (ICV) has provided for the subcontractors and fabricators. Subcontractors and fabricators need ICV to measure the progress of the work completed, to better understand and capture the status of the built environment, and to measure the quality of the fabricated components and modules. Using digital twins of the components and modules at the design phase and the construction phase, subcontractors and fabricators are capable of tracking the required information. ICV combined with some further technologies have opened some unprecedented opportunities to improve the fabrication, installation, and maintenance procedures. ICV is first investigated from the subcontractors' perspectives. Various perspectives for different trades including steel fabricators, formwork fabricators, reinforcing steel fabricators, etc., are discussed to better frame the ICV solutions for the subcontractors and fabricators. A brief summary on the state-of-the-art research and practice is also presented. It will then evaluate production monitoring at two different stages: (1) off-site production monitoring and (2) on-site production monitoring. Next, fabrication control methods and the existing technologies are then thoroughly discussed. Vision-based techniques and visual analytics for as-built status assessment and discrepancy quantification are then thoroughly discussed. Furthermore, a systematic realignment strategy for construction components is presented. Finally, a summary is provided to assess the vision-based approaches for geometric quality control and as-built status modeling in terms of accuracy and time-effectiveness. The potential of adopting the sensing technologies in subcontractors' and fabricators' practice is provided with the aim of replacing the current tape measurement practice. © 2020 Elsevier Inc. All rights reserved.	This chapter presents some opportunities that infrastructure computer vision (ICV) has provided for the subcontractors and fabricators	The potential of adopting the sensing technologies in subcontractors' and fabricators' practice is provided with the aim of replacing the current tape measurement practice. © 2020 Elsevier Inc. All rights reserved.	As-built versus as-designed, Coarse registration, Fine registration, Geometric deviation quantification, Geometric discrepancy, Laser scanning, Point cloud Registration, Modular assembly, Optimum assembly, Prefabrication accuracy, Realignment strategies, Scan versus BIM, Scan versus model comparison, Scan-to-BIM		Analysis	BIM
Sabri S.	2019	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives		10.5194/isprs-archives-XLII-4-W15-75-2019	A multi-dimensional analytics platform to support planning and design for liveable and sustainable urban environment	New urban strategies encourage compact city and higher density urban development due to unprecedented city growth and rapid urbanisation. This has led to greater attention to multi-dimensional representation, modelling and analytics of urban settings among urban planners, decision makers, and researchers. Nowadays, urban planning and urban design practitioners and scholars leverage the advancements in computer technology and multi-dimensional visualisation in examining the development scenarios from physical, environmental, social, and economic aspects. However, many urban planners still rely on two-dimensional (2D) land information and urban designers use three-dimensional (3D) graphic-based engines to asses a proposed building or assess the impact of changing development regulations. This limits the decision makers from a holistic approach through integrating the urban systems with other application domains such as transport, environmental, and disaster management to ensure the liveability of cities. This paper describes the design, and development of a multi-dimensional and spatially enabled platform to support liveability planning in Singapore. A Quantitative Urban Environment Simulation Tool (QUEST), developed in Singapore, leveraged 3D mapping data captured under the Singapore Land Authority's (SLA) 3D National Topographic Mapping project. SLA's 3D data including Building Information Model (BIM), CityGML, and other geospatial data (building footprints and land use) were processed and adapted as a service for a series of urban analytics. The paper concludes that the prerequisites for any urban environmental simulation system to be integrated with other application domains are 3D mapping data and a digital urban model, which must be spatially accurate and based on open data standards. © Authors 2019. CC BY 4.0 License.	This paper describes the design, and development of a multi-dimensional and spatially enabled platform to support liveability planning in Singapore.	The paper concludes that the prerequisites for any urban environmental simulation system to be integrated with other application domains are 3D mapping data and a digital urban model, which must be spatially accurate and based on open data standards.	3D Geospatial, BIM, CityGML, SDI, Urban Analytics, Urban Liveability	Architectural design, Disasters, Decision making, Disaster prevention, Environmental technology, Land use, Mapping, Open Data, Planning, Structural design, Three dimensional computer graphics, Urban transportation, Building Information Model - BIM, CityGML, Environmental simulation, Geo-spatial, Sustainable urban environments, Three-dimensional (3D) graphics, Urban Analytics	Design	Analytics
Madanayake U.H.	2019	Association of Researchers in Construction Management, ARCOM 2019 - Proceedings of the 35th Annual Conference			The potential of digital technology to improve construction productivity	Despite increasing adoption of digital technology in construction, productivity reports have remained disappointing. To develop insights into the reasons of this contradiction, the present paper suggests drawing on organisational competitiveness literature considering that the factors-Affecting-productivity are conveniently captured within that literature. Through a questionnaire survey, the paper analyses the views of managers in the UK construction industry regarding the effect of Building Information Modelling (BIM) and Big Data Analytics (BDA) on organisational competitiveness. The results are then traced back to the factors-Affecting-productivity for discussion. It is concluded that digitalisation enables performance improvements that can be tied to productivity gains, but this relies on the presence of certain skills and knowledge, which require training. It is also concluded that the lack of impact of digitalisation on some of the factors-Affecting-productivity may be limiting the impact of digitalisation on the overall productivity, thus leading to a stagnating productivity. © 2019 Association of Researchers in Construction Management, ARCOM 2019 - Proceedings of the 35th Annual Conference. All rights reserved.	the paper analyses the views of managers in the UK construction industry regarding the effect of Building Information Modelling (BIM) and Big Data Analytics (BDA) on organisational competitiveness.	The results are then traced back to the factors-Affecting-productivity for discussion. It is concluded that digitalisation enables performance improvements that can be tied to productivity gains, but this relies on the presence of certain skills and knowledge, which require training.	Big data, BIM, Competitiveness, Digital technology, Productivity	Architectural design, Big data, Data Analytics, Competition, Construction industry, Project management, Surveys, Building Information Modelling, Competitiveness, Construction productivity, Digital technologies, Factors affecting productivity, Productivity gain, Questionnaire surveys, UK construction industry, Productivity	Management	AI
Staples C.	2019	Association of Researchers in Construction Management, ARCOM 2019 - Proceedings of the 35th Annual Conference			Exploring the potential improvement of quality control in the construction industry with the use of digital technology	The construction industry has traditionally relied on paper to manage quality records, resulting in the capture and analysis of data being challenging, preventing historical performance analytics that lead to better outcomes. This research is aimed at critiquing the application of digital technologies for the potential improvement of quality management in the construction phase of civil engineering projects. To address the aim, two objectives emerge. The first is reviewing digital technologies that are available for use in quality control that could assist in the reduction of defects. The second is seeking the viewpoint from construction professionals to develop a quality management framework employing the most applicable digital technologies. In support of the objectives, a qualitative research approach involves multiple sources of data collection, gained from literature and interviews. Participants include digital engineering specialists, designers, main contractors and subcontractors. Applicable digital quality applications are identified as electronic document management systems, personal digital assistants, building information modelling (BIM), mobile construction application products (apps), clash mitigation using BIM, real time performance information, point clouds of as-built construction, three-dimensional vision on mobile phones and barcodes, among others. This holistic and collaborative approach facilitates personnel to make better decisions in the use of quality data. Implications for practice indicated that training, visible use of digital technologies and the provision of an effective common data environment are paramount in instigating digital applications. Employing this digital engineering in the construction phase should encourage the continuing journey to greater automation of the building activities themselves with an improvement in quality and productivity. © 2019 Association of Researchers in Construction Management, ARCOM 2019 - Proceedings of the 35th Annual Conference. All rights reserved.	This research is aimed at critiquing the application of digital technologies for the potential improvement of quality management in the construction phase of civil engineering projects.	Employing this digital engineering in the construction phase should encourage the continuing journey to greater automation of the building activities themselves with an improvement in quality and productivity.	Digital technology, Information management, Total quality management	Architectural design, Construction, Construction industry, Contractors, Personal digital assistants, Information management, Information services, Quality control, Real time systems, Three dimensional computer graphics, Total quality management, Building Information Modelling, Civil engineering projects, Construction professionals, Digital technologies, Electronic document management systems, Historical performance, Quality management frameworks, Three dimensional vision, Project management	Management	AI
Sebti I.	2019	Procedia Computer Science		10.1016/j.procs.2019.08.204	Emergency exit planning and simulation environment using gamification, artificial intelligence and data analytics	In our research, we explore methods to utilize gamified building data models and data analytics. In this paper, we present a study, where an emergency exit planning and simulation platform is implemented with a commercial center gamified data model. In the study, we compare various emergency exit location options and search the critical areas for customer evacuation. Customized user profiles are used to estimate the movement capabilities of elderly and handicapped people. The feasibility of data analytics methods for analyzing the simulation results is examined. The results show that simulations based on gamification are well-suited tools emergency exit evaluations. © 2018 Elsevier B.V. All rights reserved.	In this paper, we present a study, where an emergency exit planning and simulation platform is implemented with a commercial center gamified data model.	The results show that simulations based on gamification are well-suited tools emergency exit evaluations.	AI, BIM, Data Analytics, Gamification, Simulation	Architectural design, Artificial intelligence, Gamification, Simulation platform, Emergency exit, Planning and simulations, Simulation, User profile, Data Analytics	Design	Analytics
Sampaio A.Z.	2019	Multi Conference on Computer Science and Information Systems, MCCSIS 2019 - Proceedings of the International Conferences on Big Data Analytics, Data Mining and Computational Intelligence 2019 and Theory and Practice in Modern Computing 2019		10.33965/tpmc2019_201907c028	BIM capacities improved with VR technology in the building project	The potential of Building Information Modelling (BIM) methodology to support a transformation of the processes of design and construction has been evident in the construction industry. A current topic that requires attention is the integration of BIM with Virtual Reality (VR) where the user visualizes a virtual world through interactive devices or a total immersion. By adding VR, the BIM solution can address retrieving and preventing information and increasing efficiency on communication and problem solving in an interactive and collaborative project. BIM + VR allow two main capacities: walkthrough and consulting data, and currently BIM tools allow links to VR plugins in order to achieve both capacities. The objective of the study is to report the improvement of BIM uses with the addition of interactive capacities allowed by VR technology. © Multi Conference on Computer Science and Information Systems, MCCSIS 2019. All rights reserved.	The objective of the study is to report the improvement of BIM uses with the addition of interactive capacities allowed by VR technology. © Multi Conference on Computer Science and Information Systems, MCCSIS 2019	the integration of BIM with Virtual Reality (VR) where the user visualizes a virtual world through interactive devices or a total immersion.	BIM Methodology, VR Technology, VR+BIM Applications	Advanced Analytics, Artificial intelligence, Big data, Computation theory, Information systems, Construction industry, Data mining, Virtual reality, BIM Methodology, Building Information Modelling, Building projects, Collaborative projects, Design and construction, Presenting informations, Virtual worlds, VR technology, Architectural design	Design	BIM

Cardoso Llach D.	2019	Communications in Computer and Information Science		10.1007/978-981-13-8410-3_15	An Ecology of Conflicts: Using Network Analytics to Explore the Data of Building Design	The scale and socio-technical complexity of contemporary architectural production poses challenges to researchers and practitioners interested in their description and analysis. This paper discusses the novel use of network analysis techniques to study a dataset comprising thousands of design conflicts reported during design coordination of a large project by a group of architects using BIM software. We discuss in detail three approaches to the use of network analysis techniques on these data, showing their potential to offer topological insights about the phenomenon of contemporary architectural design and construction, which complement other forms of architectural analysis. © 2019, Springer Nature Singapore Pte Ltd.	This paper discusses the novel use of network analysis techniques to study a dataset comprising thousands of design conflicts reported during design coordination of a large project by a group of architects using BIM software.	We discuss in detail three approaches to the use of network analysis techniques on these data, showing their potential to offer topological insights about the phenomenon of contemporary architectural design and construction, which complement other forms of architectural analysis.	Architecture, BIM, Data visualization, Design ecology, Network analysis	Architecture, Data visualization, Large dataset, Ecology, Electric network analysis, Analysis techniques, Architectural analysis, Building design, Design and construction, Design coordination, Large project, Sociotechnical, Architectural design	Analysis		BIM
Xu Y.	2018	Progress in Steel Building Structures		10.13969/j.cnki.cn31-1893.2018.05.013	Analysis of Data Information Integrity in Tekla Structure Model Imported into Revit in Steel Structure BIM Revit Tekla Structure	BIM has become more concerned by the fact that BIM technology has been used as a carrier for information management innocent years,and BIM technology has been very helpful in improving project production efficiency,improving building quality,shortening construction period,and reducing construction cost.For domestic rapidly developing steel structure construction industry,BIM technology is also becoming mature.Tekla Structure and Autodesk Revit are two most popular BIM modeling softwares.The article describes how Tekla Structure and Autodesk Revit reflect the integrity of data analytics when processing model interaction through IFC files. © 2018, Progress in Steel Building Structures All right reserved.	BIM has become more concerned by the fact that BIM technology has been used as a carrier for information management innocent years,and BIM technology has been very helpful in improving project production efficiency,improving building quality,shortening construction period,and reducing construction cost.	The article describes how Tekla Structure and Autodesk Revit reflect the integrity of data analytics when processing model interaction through IFC files.	Autodesk Revit, BIM, Data exchange, IFC file, Information integrity, Tekla Structure			Management		BIM
Kakiauskas A.	2018	2018 7th International Conference on Computers Communications and Control, ICCCC 2018 - Proceedings		10.1109/ICCCC.2018.8390466	Video neuro-advertising recommender model for affective BIM	The idea of the VINERS project is to perform research on neuro-advertising by applying biometric, physiological, intelligent and affective computer technologies as well as statistical analysis, text and data analytics, recommender and multicriteria analysis methods in order to develop the Video Neuro-advertising (VINERS) Model and System. The VINERS Model is innovative on a global level by the following aspects: 1) compilation and analysis of physiological and emotional maps of advertising contents along with neuro-matrices, 2) completion of a neuro-questionnaire and 3) development of the VINERS1 Sub-model for analysing and assessing the impact of electronic advertising (advertising of contents under development) and the VINERS2 Sub-model for intuitively broadcasting an electronic advertisement (already developed contents of an advertisement). This study demonstrates the Video Neuro-advertising Recommender Model by its affective BIM basis. © 2018 IEEE.	The idea of the VINERS project is to perform research on neuro-advertising by applying biometric, physiological, intelligent and affective computer technologies as well as statistical analysis, text and data analytics, recommender and multicriteria analysis methods in order to develop the Video Neuro-advertising (VINERS) Model and System.	This study demonstrates the Video Neuro-advertising Recommender Model by its affective BIM basis.	Affective BIM, Affective Computing, Recommender Model, Video Neuro-advertising	Marketing, Physiological models, Physiology, Affective Computing, Affective BIM, Affective computer, Data analytics, Electronic advertising, Multi Criteria Analysis, Submodels, Recommender systems	Analysis		BIM
Pyo K.	2018	ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things			Research trend analysis for construction automation	Automation has been an active research topic in the construction industry for many years to improve the accuracy, reliability, and efficiency of the construction process. This study identifies global research trends in automation in construction during the past 15 years by analyzing papers published in the journal Automation in Construction. Text mining, data clustering, and keyword network analysis were applied to identify emerging technologies. According to the clustering of the most recent three years' research, the main topics fall into seven categories: BIM(building information modeling), optimization, data acquisition, big data and AI, 3-D printing, wearable devices, and others. Over the various regions and periods, the results showed that the research focus has shifted from traditional mechanical automation to construction data acquisition, management, and analysis, introducing a new historical period in construction automation. © ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things. All rights reserved.	This study identifies global research trends in automation in construction during the past 15 years by analyzing papers published in the journal Automation in Construction.	Over the various regions and periods, the results showed that the research focus has shifted from traditional mechanical automation to construction data acquisition, management, and analysis, introducing a new historical period in construction automation.	Construction automation, K-means clustering, Keyword network, Text mining, Trend analysis	Automation, Big data, Construction industry, Clustering algorithms, Construction, Data acquisition, Data mining, Robotics, Construction automation, K - means clustering, Keyword networks, Text mining, Trend analysis, Architectural design	Design		AI
Gerrish T. (N E)	2018	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)		10.1007/978-3-319-91635-4_31	Visual pattern recognition as a means to optimising building performance?	The move towards the use of smart systems to record data about the performance of building presents an opportunity to examine patterns of behaviour, which shed light on its performance peaks and troughs. Answers often lie in unusual activity, such as troughs. For example, smart systems are used to record in-use data such as room temperatures, thermal comfort, and lighting usage. Each system is designed for an expected 'behaviour pattern' that is bounded by a 'threshold' boundary. This is the expected performance the system is designed for. Any deviations in this performance may indicate of a system malfunction, its overuse or underuse due to unexpected usage of building space/s (e.g. large number of visitors, doors/windows being left open). Performance when bounded within the threshold limits would be considered to be 'normal' or 'expected'. Thus, answers fall within four categories of performance behaviours. These include system malfunction, system overuse, system underuse, and normal performance. As data and information are accumulated over a period of time they present opportunities to observe system behaviour patterns and present opportunities to map these patterns and classify within learning clusters of 'expected' and 'unexpected' thresholds. Doing so would enable building owners to truly understand the building, so performance can be firstly understood and then optimised. Thus, an unusual activity that is significantly beyond the expected 'norm' would present an opportunity to learn about the building so a healthy function can be determined and maintained. The generation of large datasets through extensive monitoring has created a potential environment in which big-data style analytics could be applied for holistic performance assessment and pattern recognition. This research builds on the work previously completed by Gerrish et al. [1–4, 21] and utilises techniques of visualisation to demonstrate such behaviour patterns and presents learning opportunities for optimal performance. This is demonstrated through visualisation of energy performance data for a case-study building in the UK. © Springer International Publishing AG, part of Springer Nature 2018.	This research builds on the work previously completed by Gerrish et al. [1–4, 21] and utilises techniques of visualisation to demonstrate such behaviour patterns and presents learning opportunities for optimal performance	This research builds on the work previously completed by Gerrish et al. [1–4, 21] and utilises techniques of visualisation to demonstrate such behaviour patterns and presents learning opportunities for optimal performance.	BIM facilities, Energy performance management, Management, Visualisation	Architectural design, Big data, Classification (of information), Intelligent computing, Energy efficiency, Engineering research, Management, Visualization, Building performance, Data and information, Energy performance, Learning opportunity, Optimal performance, Performance assessment, Performance of buildings, Visual pattern recognition, Pattern recognition	Management		Analytics
Ng S.T.	2018	Construction Research Congress 2018: Infrastructure and Facility Management - Selected Papers from the Construction Research Congress 2018		10.1061/9780784481295.033	A social networking enabled crowdsourcing system for integrated infrastructure asset management	Emerging information and communication technologies like building information modeling, internet of things, social networking, cloud computing, big data analytics, mobile application and so on serve as important catalysts to transform the practices of infrastructure asset management (IAM). Owners, occupiers, managers, operators and contractors of infrastructure facilities can now capture, process, share, integrate, and analyse data related to various infrastructure facilities collaboratively and cooperatively to achieve an integrated whole life cycle IAM. This should help improve the overall efficiency of a community and/or city through optimized resource allocation, reduced maintenance and refurbishment cost less energy consumption lower risks of service disruption increased transparency and better strategic, tactical and operational decisions. This paper outlines the development of a social networking enabled crowdsourcing system for integrated IAM. The system is designed to satisfy the requirements of different stakeholders in managing, operating and repairing a series of interdependent infrastructure facilities. Preliminary studies on the residential sector of Hong Kong reveal that the system could help improve the communication between stakeholders, enhance the transparency and effectiveness of asset management, and reduce the risks of bid-rigging in the repair and maintenance schemes. By integrating the proposed system with the existing systems being adopted throughout the entire building life cycle, such as the building information modeling and asset management systems, facility condition, and usage data that is difficult to obtain through traditional means can now be crowdsourced, co-created, or co-processed for facility performance analysis, complaint analysis, and service scheduling analysis. © 2018 American Society of Civil Engineers (ASCE). All rights reserved.","Building maintenance Crowdsourcing Integrated facility management Renovation and refurbishment Social networking	This paper outlines the development of a social networking enabled crowdsourcing system for integrated IAM.	By integrating the proposed system with the existing systems being adopted throughout the entire building life cycle, such as the building information modeling and asset management systems, facility condition, and usage data that is difficult to obtain through traditional means can now be crowdsourced, co-created, or co-processed for facility performance analysis, complaint analysis, and service scheduling analysis.	Building maintenance, Crowdsourcing, Integrated facility management, Renovation and refurbishment, Social networking	Architectural design, Asset management, Distributed computer systems, Big data, Crowdsourcing, Energy utilization, Information theory, Life cycle, Office buildings, Repair, Scheduling, Social networking (online), Social sciences computing, Transparency, Building Information Model - BIM, Building maintenance, Facility management, Information and Communication Technologies, Infrastructure asset management, Integrated infrastructure	Management		Analytics
Rubin D.K.	2017	ENR (Engineering News-Record)			Mining big data is 'sexy' arena	Construction-sector companies and software firms are embracing data science with vastly improved tools to collect and store enormous amounts of data collected from project stakeholders and the growing need to analyze and interpret it for public-infrastructure project management and planning. The efforts are making a difference for owners. Rocky Kearney, deputy director of New Mexico's Public School Facilities Authority, estimates that the authority's use of a cloud platform, hosted by Plantation, a software firm e-Builder, has saved it $200 million in maintenance and capital costs for the $19.5 billion in assets of its 89 districts. The city of Toronto's transportation services group created a new Big Data innovation team in 2015 to leverage emerging transportation data sets, in particular GPS probe-based data sources. The U.S. Dept. of Energy's Los Alamos National Laboratory in New Mexico standardized on a Locus Technologies cloud-based platform to manage environmental compliance and monitoring for multiple stakeholders of a nearly 40-sq-mile site where radioactive and chemical contamination occurred during more than seven decades of nuclear-weapon production and research. Contracting giant Bechtel has created Big Data & Analytics Center of Excellence at its Reston base to access and harness this volume of information, learn from it and use the knowledge gained to transform the way we operate and compete. Design firm Merrick used a LIDAR scan of an existing power substation to build the BIM model and subsequent construction documents for an electrical infrastructure upgrade.	science with vastly improved tools to collect and store enormous amounts of data collected from project stakeholders and the growing need to analyze and interpret it for public-infrastructure project management and planning.	Design firm Merrick used a LIDAR scan of an existing power substation to build the BIM model and subsequent construction documents for an electrical infrastructure upgrade.	Architectural design, Construction industry, Data mining, Environmental technology, Nuclear weapons, Project management, Construction documents, School buildings, Cloud based platforms, Electrical infrastructure, Environmental compliance, Los Alamos National Laboratory, Multiple stakeholders, Public infrastructure project, Transportation services, Big data			Management		Analytics
Long S.	2017	Digital Proceedings of the 24th EG-ICE International Workshop on Intelligent Computing in Engineering 2017			Using BIM throughout the occupancy of residential buildings to benefit homeowners: A roadmap to viability	This paper considers how homeowners can benefit from the use of Building Information Modelling (BIM) during the occupancy phase of residential buildings, and the issues that may arise, alongside the authors' proposed solutions. Four key deliverables have been considered, economic, social and environmental benefits, and the facilitation of efficient information management. These deliverables are to be achieved through home automation, the availability of building information, virtual house viewings and big data analytics. The core issues are considered to be user accessibility, ownership and viability. A ""Home BIM"" cloud application has been proposed as a workable solution. The application is based on a data-rich BIM model, enhanced with occupancy data using the Internet of Things (IoT). The outputs discussed include instructing actuators for home automation, and accessible information and functions displayed via a user-friendly interface. A roadmap to delivering such an application has been presented.	This paper considers how homeowners can benefit from the use of Building Information Modelling (BIM) during the occupancy phase of residential buildings, and the issues that may arise, alongside the authors' proposed solutions.	The outputs discussed include instructing actuators for home automation, and accessible information and functions displayed via a user-friendly interface. A roadmap to delivering such an application has been presented.	Big data Buildings, Housing, Information management, Intelligent computing, Building information Modelling, Internet of things, Accessible information, Cloud applications, Home automation, Internet of thing (IOT), Residential building, Social and environmental, User friendly interface, Architectural design			Management		BIM
Puuwppi R.	2017	CAADRIA 2017 - 22nd International Conference on Computer-Aided Architectural Design Research in Asia: Protocols, Flows and Glitches			Enabling customer choice in housing	This paper presents a live and tested solution that enables home buyers to choose and customise their future homes in a web browser. It allows future owners and residents to configure and visualise their home in 3D but also keep it affordable by displaying the construction costs back to users in real-time. The proposed solution is analysed in the context of current housing market, exciting web and BIM technologies and compared to currently available solutions. Additionally, we have been tracking visitor behaviour by using web analytics and can draw some conclusions about its performance. © 2017, The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.	This paper presents a live and tested solution that enables home buyers to choose and customise their future homes in a web browser.	The proposed solution is analysed in the context of current housing market, exciting web and BIM technologies and compared to currently available solutions.	Combinatorics, Configurators, Housing, Mass customisation, Web technologies	Housing, BIM technologies, Construction costs, Combinatorics, Configurators, Customer choice, Housing markets, Mass customisation, Web technologies, Architectural design	Design		Analytics
Perfsuru S.	2016	Proceedings of the 21st International Conference on Web3D Technology	Web3D 2016	10.1145/2945292.2945321	A plant engineering "digital rosetta stone": Towards data-centric multidimensional CAD web portal	Engineering design phases in AEC1 and process industry projects produce large amounts of virtual CAD data that have to be linked together, specifically in the case of nuclear power plants, before being realized in the implementation and construction phases. In this Engineering design phases in AEC1 and process industry projects produce large amounts of virtual CAD data that have to be linked together, specifically in the case of nuclear power plants, before being realized in the implementation and construction phases. In this poster we propose our ""Digital Rosetta Stone"" web portal founded on two innovative pillars: A graph database and its agile connection to MOSAIC, a Visualisation Analytics Engine integrating Visual Computing as a Service to mix 1D, 2D and 3D engineering data in a full data-centric and web-Accessible way. © 2016 ACM.	In this poster we propose our ""Digital Rosetta Stone"" web portal founded on two innovative pillars: A graph database and its agile connection to MOSAIC, a Visualisation Analytics Engine integrating Visual Computing as a Service to mix 1D, 2D and 3D engineering data in a full data-centric and web-Accessible way.	A graph database and its agile connection to MOSAIC, a Visualisation Analytics Engine integrating Visual Computing as a Service to mix 1D, 2D and 3D engineering data in a full data-centric and web-Accessible way	2D Mechanical Schema (P&ID), BIM, CAD Massive Model Visualization (MMV), Digital Plant Mock-up, GITF, Graph Database, SRC, Neo4j, Responsive Web, SVG, Visual Analytics (VA), Visual Computing as a Service (VCaaS), X3D, X3dom	Architectural design, Nuclear power plants, Portals, Visualization, Web services, Websites, GITF, Graph database, Model visualization, Neo4j, Responsive Web			Design		Analytics
Jones S.	2015	ENR (Engineering News-Record)			Component design moves beyond standard prefab	Prefabrication is creating next-generation change in the fast, efficient delivery of complex buildings. Recent growth in the use of BIM and model-based processes has spawned an enormous increase in offsite and near-site prefabrication, a trend that could be transformative for the construction industry. A new SmartMarket report published by Dodge Data & Analytics reveals that general contractors are reporting extensive use of model-driven prefabrication.	Recent growth in the use of BIM and model-based processes has spawned an enormous increase in offsite and near-site prefabrication, a trend that could be transformative for the construction industry. A new SmartMarket report published by Dodge Data & Analytics reveals that general contractors are reporting extensive use of model-driven prefabrication.	A new SmartMarket report published by Dodge Data & Analytics reveals that general contractors are reporting extensive use of model-driven prefabrication.	Construction industry, Complex buildings, Component design, General contractors, Model-based OPC, Model-driven Architectural design			Design		BIM
Redmond A.	2015	International Conference on Civil, Structural and Transportation Engineering			Employing an exploratory research stage to evaluate green building technologies for sustainable systems	In many industries an exploratory research stage is employed to study new ideas or enabling technologies that may mature into a 'system-of-interest'. This approach to designing an energy optimising product and service systems leads to challenging attributes because of the broad range of economic, environmental and social factors that are presented throughout the life-cycle of production. This paper reviews the key decision factors presented during the initial phase of the production of a lifecycle model for an ambitious research and development project (Green 2.0). The Green 2.0 project aims at exploiting advances in (i) Building Information Models (BIM), (ii) Online Social Networks (OSN) and (iii) Big Data technologies, to design and develop an interactive data-driven middleware for socio-technical analysis of green buildings. The main technical objective of the paper is to highlight green building technologies featuring advancements in virtual parametric models for creating an integrated technical analysis environment, while at the same time engaging end-users and harnessing their collective knowledge in building design. The paper adheres to a formal system engineering approach in order to identify the scope of the system, investigate alternative system design concepts, explore data collection methods and assess the relevant emerging technologies. © 2020, Avestia Publishing. All rights reserved.	The main technical objective of the paper is to highlight green building technologies featuring advancements in virtual parametric models for creating an integrated technical analysis environment, while at the same time engaging end-users and harnessing their collective knowledge in building design.	The paper adheres to a formal system engineering approach in order to identify the scope of the system, investigate alternative system design concepts, explore data collection methods and assess the relevant emerging technologies. © 2020, Avestia Publishing. All rights reserved.	BIM, Green Architecture, Middleware, Social Networks Analytics, System Integration			Analysis		BIM

Wang B.	2013	European Group for Intelligent Computing in Engineering, EG-ICE 2013 - 20th International Workshop: Intelligent Computing in Engineering			Add one more dimension to building conceptual design-fire evacuation	Building Information Modelling (BIM) promotes integration and collaboration, which means ideally different stage applications during building life cycle should be effectively ,linked through shared data, information and process. However, while paying much attention to design collaboration and subsequently economic benefit, BIM should not neglect the aspect of how to create a reasonable building design for human safety in extreme environment. This is especially particularly significant in addressing fire disaster which is too common and related to lives and property safety of all occupants in the building. Although recent research has provided some novel technologies combining emergency human behaviour with simulation technology, challenges is to focus on the effective way of precisely representing human behaviours in emergency and effective information interaction between the building and the human characters. The focus in this paper lies on how to utilise BIM as a building information provider to work with virtual reality technology to build an adaptable immersive serious game to explore fire evacuation behaviours and produce unique evacuation ontologies for the building design, and then employ virtual characters with artificial intelligence (AI) based on these ontologies to testify the corresponding building designs for fire evacuation.,linked through shared data, information and process. However, while paying much attention to design collaboration and subsequently economic benefit, BIM should not neglect the aspect of how to create a reasonable building design for human safety in extreme environment. This is especially particularly significant in addressing fire disaster which is too common and related to lives and property safety of all occupants in the building. Although recent research has provided some novel technologies combining emergency human behaviour with simulation technology, challenges is to focus on the effective way of precisely representing human behaviours in emergency and effective information interaction between the building and the human characters. The focus in this paper lies on how to utilise BIM as a building information provider to work with virtual reality technology to build an adaptable immersive serious game to explore fire evacuation behaviours and produce unique evacuation ontologies for the building design, and then employ virtual characters with artificial intelligence (AI) based on these ontologies to testify the corresponding building designs for fire evacuation.	The focus in this paper lies on how to utilise BIM as a building information provider to work with virtual reality technology to build an adaptable immersive serious game to explore fire evacuation behaviours and produce unique evacuation ontologies for the building design, and then employ virtual characters with artificial intelligence (AI) based on these ontologies to testify the corresponding building designs for fire evacuation.,linked through shared data, information and process.	Although recent research has provided some novel technologies combining emergency human behaviour with simulation technology, challenges is to focus on the effective way of precisely representing human behaviours in emergency and effective information interaction between the building and the human characters.	Behavioral research, Buildings, Conceptual design, Fires, Intelligent computing, Life cycle, Building Information Modelling, Social sciences, Virtual reality, Design collaboration, Extreme environment, Information interaction, Information provider, Integration and collaboration, Simulation technologies, Virtual reality technology, Architectural design		Design	BIM
Chasnar A.	2011	Designing Together: CAADFutures 2011 Proceedings of the 14th international conference on Computer Aided Architectural Design			Navigating complex models in collaborative work for integrated (and sustainable) design	The paper discusses geometric-content-based search and classification techniques proposed in order to support collaborative, multi-disciplinary work on building design projects which utilize three-dimensional digital models (e.g. BIM, CAD, CAE, etc.) The rationale for employing such techniques – as an alternative to conventional assigned-attribute-based ones – is presented, based on observed difficulties experienced by users of digital models prepared by parties other than themselves. Also introduced are proposed methods drawing on the field of visual analytics for displaying the results of search and classification operations by augmenting the conventional system of views and tabular information in order to enable users to obtain greater insight into the contents of complex models. Included is a description of preliminary tests undertaken to assess the validity of some of these proposals, and results showing that model users are able to apply the proposed methods for retrieval and organization of information in models, thus overcoming some language-based and other common obstacles typically encountered with exchanged models in collaborative design processes. © P. Leclercq, A. Heylighen and G. Martin (eds).	The paper discusses geometric-content-based search and classification techniques proposed in order to support collaborative, multi-disciplinary work on building design projects which utilize three-dimensional digital models (e.g. BIM, CAD, CAE, etc.)	Included is a description of preliminary tests undertaken to assess the validity of some of these proposals, and results showing that model users are able to apply the proposed methods for retrieval and organization of information in models, thus overcoming some language-based and other common obstacles typically encountered with exchanged models in collaborative design processes.	Classification (of information), Computer aided design, Search engines, Classification technique, Collaborative design process, Collaborative Work, Organization of informations, Content-based search, Conventional systems, Three-dimensional digital models, Visual analytics, Architectural design		Design	BIM
										Total	151		