

# ECPPM 2021

## CONFERENCE PROGRAMME & BOOK OF ABSTRACTS

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Conference Organisers:



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# PREFACE

As new social, economic, environmental changes, including dramatic epidemic challenges, occur, the role of digital technologies becomes increasingly influential, especially in the development of the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry. They allow a new perspective for sustainable evolution of urban environments and infrastructures that are permanently growing and becoming more complex. Although the digital transformation of the building industry has been an ongoing process over several decades, often hidden under the moniker of Building Information Modelling (BIM), the progress in development and practical adoption of digital technologies does not fully meet the expectations. It certainly has much greater potential that will be realized in the coming years.

The first organizations to introduce digital innovations have good chances to be leaders of the AEC/FM industry. The formula to achieve success and competitive advantage, apparently, is based on the same imperatives that are recommended by Gartner for any organizations adopting digital technologies. These imperatives are dynamism, privacy, augmented intelligence, culture, product management and digital twin; they definitely have need for emerging Information and Communication Technologies (ICT).

Dynamism is crucial for the organization's adaptability and its potential to improve business processes and increase productivity. ICT technologies bring new capabilities and new ways for AEC/FM organizations to succeed. However, rational adoption of the technologies still remains a challenging problem, to a significant degree, due to the multi-disciplinary nature of projects, large volumes of information and its heterogeneity, computationally hard optimization problems, involvement of numerous stakeholders, variety of used software tools and platforms, legacy data to be maintained throughout the entire project lifecycle (design, engineering, construction, operation, demolition), insufficient levels of standardization, regulation and legislation. These factors prevent the direct use of general-purpose ICT technologies, and the latter must be essentially improved or adapted to meet these requirements. This circumstance opens up a wide field for further research and development.

Modern ICT technologies for management of databases, documents, revisions, workflows, and requirements remain a priority. The need to share information among project participants with own roles, expertise, skills leads to the problem of information consistency and trustworthiness. Involvement of the participants separated geographically, organizationally and technically only exacerbates the problem. Being exchanged, replicated, transformed, and updated in an uncoordinated manner, the information loses consistency and integrity, which makes it useless for further interpretation and processing by BIM tools. The development and deployment of advanced CDE (Common Data Environment) servers providing solid transaction guarantees ACID (Atomicity, Consistency, Isolation and Durability) and BASE (Basically Available, Soft state, Eventually consistent) seems to be a promising approach to management of semantically complex information, combining both BIM data driven by a formally specified schemata and complementary semi-structured or unstructured documents.

BIM interoperability also remains a critically important and still unresolved issue. It relates to the ability of BIM software applications and users to exchange and share project information freely. A rather disappointing experience with openBIM standards by buildingSMART alliance and, particularly, with IFC files has forced the proponents to acknowledge the difference between enabling applications to exchange data (the so-called technical and semantic interoperability), and the desired substantive property of applications to coherently interact with each other while keeping data complete, consistent and meaningful (conceptual interoperability). To move towards this goal and ensure the conceptual interoperability of IFC-compliant applications, not just technical and semantic ones, standardization and certification activities should be thoroughly reviewed.

It is worth acknowledging that the IFC standard seems to be the best solution for achieving the real interoperability between BIM applications produced by different software vendors. It is gratifying to see that the IFC standard continues to evolve, covering more infrastructure applications complementary to traditional disciplines. At the same time, alternative approaches to integrated data management are also being proposed and elaborated. These are federated databases, ontologies for separate BIM disciplines

and aspects, linked data technologies, document-oriented information containers. However, they cause extremely hard issues of data consistency, concurrent access, change control, the resolution of which seems still rather nontrivial. All of the above approaches need formal methods to validate and certify software applications, otherwise interoperability can simply be declared, but can never be guaranteed.

The project information privacy is another fundamental problem. Inability to successfully manage privacy puts the entire digital transformation of AEC/FM organizations at high risks. Many employers do not want to give up safety, confidentiality and peace of mind in exchange for convenience and ability to freely share information with partners when collaborating together on multidisciplinary projects. Cryptography, block-chain, and smart contracts are just some of the technologies that need careful validation before being widely adopted into industrial practice.

AEC/FM industry is encouraged to follow the latest ICT technologies like the Internet of Things (IoT), Big Data, Artificial Intelligence (AI), cloud computing, which are often employed together to bring the Digital Twin (DT) paradigm. Being a cyber-physical system (CPS), which integrates computation, control and communication facilities, DT reveals new perspectives on managing the construction, operation and maintenance of the building and its assets. A high level of fidelity is reached by gathering data about physical world objects in real-time and automatically converting it into respective digital models. The behavior of the physical objects can be investigated and predicted under changing conditions, proper management decisions are taken to optimize objective functions. DT technologies have a lot of applications for AEC/FM industry. They allow stakeholders to continuously monitor real progress on the construction site against the initial BIM-based planning, to control energy performance of the building under different operation modes and occupation factors, to manage building assets. The methods that can significantly improve the building construction and operation have been well studied, but the services that implement them need more modern deployment platforms and highly automated configuration tools, sometimes called DT factories.

Being scaled up to the city level, digital twins can help in optimizing traffic in urban environments, controlling pedestrian flows in crowded places, managing energy consumption, monitoring air pollution, and so on. Smart cities and smart buildings managed using digital twins are expected to provide better service, improved quality of life and a sustainable future. While BIM is focused on individual buildings, the need of the information integration at the city level and the resulting amalgamation of BIM and City Information Modelling (CIM) become more obvious. However, this aspect is not explored in its full potential yet. Diverse information standards, different computation models and methods should be reviewed and, likely, harmonized to bridge the gap between BIM and CIM technologies.

The information acquisition is necessary for the functioning of CPS services and digital twins. Different sorts of sensors and IoT devices, integrated with BIM and CIM, seem to be the logical choice for monitoring infrastructures and building assets during construction and operation stages. Complementary methods of photogrammetry, laser scanning with point clouds and aerial drone captures have been gaining traction in monitoring urban environments and construction sites. Obtained semi-structured data such as time series, photos, videos and point clouds lacks concise semantics, raising many difficulties when interfacing with BIM and CIM models. Semantic recovery and enrichment of sensed and scanned data is a computationally hard problem often resolved using AI methods. The management of big spatial-temporal data is another serious problem requiring thorough research on special-purpose databases.

As the pressure on the global climate and resources is constantly increasing due to population growth and intensified human activities, more and more attention is paid to sustainable development – a foundational principle that implies ensuring of a civilized quality of life for the future generation. Indeed, being a significant resource consumer, the AEC/FM industry is responsible for significant shares of the total energy use, global greenhouse gas emissions, total waste and raw material. Currently, most of the efforts within the industry are focused on new methods to acquire and use resources within so-called circular economy. It implies studying products, improving processes, increasing energy efficiency, managing supply chains to minimise wasted resources. However, all these efforts are still to be adopted at a larger scale.

Sustainability is a quite complex concept covering both social, economic and environmental pillars and admitting different assessments and criteria such as design quality, functionality, comfort and health, floor

area, spatial program, building cost and life-cycle cost, solar insolation, heating/cooling load, energy use intensity and global warming potential. To meet these criteria, different mathematical models, computation, simulation and optimization methods can be effectively employed. At the same time, as some criteria are subjective assessments, the role of social surveys still remains important.

In recent years, AI methods and tools have become an indispensable part of civil engineering, construction management, building operation control and are facing ever new applications. Regardless of what principles the methods are based on: neural networks, swarm intelligence, machine learning, metaheuristics such as evolutionary algorithms, ant colony, simulated annealing; the methods enable solving wide classes of problems of global optimization, reasoning and decision making, clustering and data mining, recognition and classification. Not aiming to provide a comprehensive panorama of AI methods and applications for the AEC/FM industry, we are pleased to present dedicated papers and surveys focusing on AI methods for such actual problems as structural damage detection, optimization of structural design, building code compliance checking, and analysis of semi-structured data. Unfortunately, little attention is paid to the issues of augmented intelligence which is the logical step beyond artificial intelligence in the AEC/FM and, according to Gartner, it will change jobs putting employers side by side with advanced artificial intelligence systems, process and robotics and making new jobs more meaningful and rewarding.

Finally, although mentioned last, culture is identified as the largest barrier to realizing the promise of digital transformations. Culture is not just social behavior and norms, but also the knowledge, beliefs, arts, laws, customs, capabilities, and habits. As culture is acquired through the learning processes, dissemination of the best practices, presentation of emerging ICT technologies at scientific and practical forums, standardization and legislation efforts, new education formats are all of great interest and importance.

This programme collects abstracts of the papers presented at the 13th European Conference on Product and Process Modelling (ECPM 2021, Moscow, 15–17 September 2021). Covering a wide spectrum of thematic areas overviewed above, the papers are devoted to critically important problems arising on the ongoing way of digital transformations in the AEC/FM industry. High quality contributions hold great promise towards the advancement of research and technological development targeted at the digitalization imperatives.

I want to thank the chairman and founder of the ECPM conference Prof. Raimar Scherer, the members of the scientific committee whose comments contributed to the quality of the presented papers, my colleague Vasily Shutkin who took over a significant part of the organizational work, and, of course, the authors who found the opportunity, strength and inspiration to complete and present exciting research results in such a difficult and strange time.

Sincerely yours,

Prof. Dr. Vitaly Semenov

# COMMITTEES

## STEERING COMMITTEE

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Raimar Scherer, Technische Universität Dresden, Germany

Prof. Dr.-Ing. Raimar J. Scherer is Senior Professor at the Institute of Construction Informatics at the Technical University Dresden responsible for the research. He headed the Institute in 1994–2017. He has more than 35 years of experience in construction IT, including 7 years as full professor for CAD/CAM and structural reliability at the University of Karlsruhe and several years of practice in the construction industry including ICT consultancy and a one-year residency with a world leading CAD provider. His research activities include the broad spectrum of construction ICT aspects. He has been involved in 25 BIM related EU and 20 German research projects, of which he co-ordinated 16. He has been a member of the multimodel group of ISO 21597 since 2017 and was member

### Vice Chairperson



Vitaly Semenov, Ivannikov Institute for System Programming, Russian Academy of Sciences, Russia

Prof. Dr. Vitaly Semenov has headed the Department of System Integration and Multi-Disciplinary Applied Systems at the Ivannikov Institute for System Programming of the Russian Academy of Sciences since 2015. His main research interests focus on model-driven software engineering methodologies and CASE toolkits for creating advanced digital platforms and integrated systems that meet the requirements of multi-functionality, multi-modality, scalability, interoperability, portability and deployment in heterogeneous environments. He has led more than 25 Russian and international R&D projects and has published 150 articles on fundamental topics of software engineering, data management, computer graphics, and operations research. He is a Professor for computer science at the Moscow Institute of Physics and Technology, and the Higher School of

Economics, both leading Russian State Universities. For more than 20 years he has been giving lectures on software and information visualization. Emerging BIM technologies are of particular interest. From 2007 to 2017 he directed the development of 4D modeling and planning system at Synchro Software Ltd. He developed innovative methods for spatial-temporal project planning, near-optimal project scheduling, effective rendering of large pseudo-dynamic scenes, and semantic reconciliation of replicated data, which made it possible to provide competitive advantages of the system. Currently, it is a popular software product that has been successfully used by hundreds of companies around the world to visually plan and manage complex construction projects and large infrastructure programs.

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### Chair



Prof. Vera V. Galishnikova, Prorector, International department, Moscow State University of Civil Engineering (MGSU), Moscow, Russia

Vera V. Galishnikova is the Prorector of the Moscow State University of Civil Engineering and the Head of the Department of Civil Engineering of the RUDN University. She serves as an Academician since 1991. In the past Dr. Galishnikova served in Volgograd State University of Architecture & Civil Engineering (Russia) and Michigan State University (USA).

Prof. Vera Galishnikova took her engineering education in Saratov State Polytechnic Institute (Saratov, Russia), and specialized in Civil Engineering. She received her first PhD degree from the Moscow Institute of Civil Engineering in 1991, and in 2004 second PhD degree from the Michigan State University. Prof. Galishnikova received her

DSc degree from the Supreme Attestation Commission of Russian Federation in 2016.

Computational Civil Engineering; Building information modelling; Topological computer models of buildings; Computational mechanics of complex steel structural systems – latticed plates and shells, thin-walled plate and plate-rod structures; Nonlinear finite element analysis of space frames; Nonlinear stability of structures; Structural renovation and complex modernization of buildings etc. are the main fields of her research.

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# KEYNOTE SPEAKERS



**Philipp Nikandrov**

GORPROJECT, Moscow, Russia

**Title: BIM-based Design of Megatall Projects: Lakhta Center Case**

**Abstract:**

Lakhta Center in Saint-Petersburg, Europe's tallest building and the world's northernmost supertall skyscraper was possibly the most complex object the world to design and build. With non-orthogonal geometry, curved helix/spiral façade envelopes and non-repetitive floors (neither of floors plans repeat each other) this project would probably take few decades to design and deliver by conventional ways, that designers and engineers used to operate before BIM and 3D-modelling replaced the drawing boards. To withstand some of the most extreme climate conditions in Europe while exceeding Russia's rigorous energy and safety requirements and achieving LEED Platinum certification—was an ambitious task for design and engineering. Architecturally organic form of the Lakhta Center tower consists of five wings that twist almost 90 degrees (0.82 degrees per floor), tapering to the very top of the spire - so none of its 89 floors repeat, and this inhabitable sculpture's extremely complex geometry can only be handled through 3D modeling and BIM software, as vitally important toolkit, that helped to avoid a large number of serious mistakes during design and further installation. The team constantly worked out the geometric conflicts between different elements and systems in the design process. Ultimately, designing the Lakhta Center was a tremendous challenge: there were so many unique elements—architectural, structural, and engineering—so we had to develop more than 6,000 new Revit families. The BIM model was developed with an LOD of 400 and immediately after its completion it was passed to the owner for operation and maintenance to continue its post-construction mission.

**Biography:**

With 25 years of international experience in architecture and masterplanning Philipp Nikandrov is a leading Russian architect with substantial expertise in large scale, complex and unique projects of high-rise typology. His design approach creates the route between contextualism and minimalism, reaching the complexity through simplicity. The strong identity in his concepts is always rooted in architectural metaphors derived from site context, history of the place and cultural background of the project in a way that the final form creates the symbol, project logo and recognizable icon on the skyline.

Since joining international company RMJM in 1997 Philipp served as senior designer and project architect in some of the most prestigious projects, working in the firm's offices in UK, Middle East and later in Russia. In 2011 after ending his 15 years international career in RMJM as director and European Studio co-principal Philipp joined the leading Russian design company GORPROJECT as its chief architect and principal designer, managing few high-rise projects in Moscow and Saint-Petersburg. As design team leader Philipp successfully participated in many prestigious international and regional design competitions, and one of the most notable amongst his large-scale projects from competition to realization was Okhta Centre (2006-2010) and later Lakhta Centre (from 2011) - Gazprom HQ in Saint-Petersburg with 465m tower component, which is currently under construction and will rank as Europe's tallest skyscraper targeting LEED Gold certification for its achievements in sustainable design.

As chief designer and project architect Philipp has delivered the iconic Evolution Tower from its earlier concept to completion (2004-2015). The jewel of Moscow City high-rise cluster Evolution Tower received many international and national awards (second place in Emporis Skyscraper Awards in 2016, the featured finalist of 2015 CTBUH Best Tall Building Awards and finalist of MIPIM Award 2016, etc).

Philipp is currently working on the design of adjacent plot, where civic piazza with amphitheatre forms the main open public space of Moscow City business downtown with its centerpiece building, featuring the world's largest clock observed from the surrounding towers.

Philipp Nikandrov is an author of many high-profile publications and participant of architectural exhibitions and international conferences such as CTBUH, UNESCO World Heritage, Forum 100+, Skyscrapers Asia Summit 2017 in Singapore (as its chairman).



Franz Baader, Prof. Dr.-Ing.

Technische Universität Dresden, Dresden, Germany

Title: A Description Logic Journey

#### Abstract:

Description Logics (DLs) are a well-investigated family of logic-based knowledge representation formalisms, which are frequently used to formalize ontologies in various application areas such as the Semantic Web, biology, medicine, mechanical engineering, chemical process engineering, civil engineering, and situation recognition. An important design goal when developing a DL is to find a good compromise between the expressive-ness of the representation language and the complexity of reasoning (i.e., computing implicit consequences of the formal statements in the ontology). In the first wave of DL research, the trend was to go towards more expressive DLs by adding new concept constructors, which were motivated by specific applications, but turned out to be useful also in other domains. Whereas reasoning in the obtained expressive DLs had a high worst-case complexity, highly optimized DL systems nevertheless behaved well in practice. With the adoption of the DL-based standard ontology language OWL, the number and the size of ontologies grew rapidly, which made efficient reasoning all the more important. This triggered a second wave of DL research, in which lightweight DLs with tractable reasoning problems (i.e., ones solvable in polynomial-time) were designed, such as the members of the EL family. Another trend was that ontology-based reasoning about data became more important, which led to the development of the DL-Lite family of DLs, which allowed reducing reasoning about data with respect to DL-Light ontologies to answering relational database queries. It then became apparent that the specialized algorithms developed for lightweight DLs, such as the consequence-based reasoning procedures for EL, could also be adapted to more expressive DLs. Although these algorithms are then no longer guaranteed to run in polynomial time, they show a “pay as you go” behavior, i.e., they can deal with the expressive language, but are the more efficient the less “costly” concept constructors are used in the ontology. Due to the research efforts of the last 30 years, the DL community can now offer a large portfolio of different representation languages and reasoning systems to ontology engineers and users of ontologies, from which they can choose the language and system that best fits the application at hand.

#### Biography:

Franz Baader is full Professor for Theoretical Computer Science at TU Dresden (Germany) since 2002 and Director of the Institute for Theoretical Computer Science at TU Dresden since 2005. From 2012 to 2016 he was Dean of the Faculty of Computer Science of TU Dresden. He has received his doctoral degree (Dr.-Ing.) in Computer Science from the University of Erlangen Nürnberg in 1989, and from 1989 to 1993 was Senior scientist and Project leader at the Germany Research Center for Artificial Intelligence (DFKI) in Kaiserslautern and Saarbrücken. From 1993 to 2002 he was professor for Theoretical Computer Science at RWTH Aachen.

His main research area is Logic in Computer Science, and there in particular Automated Deduction and Knowledge Representation. He and his research group have worked on Description Logics for 30 years, and have laid the logical and algorithmic foundations for the Description Logics underlying OWL and the OWL 2 profile OWL 2 EL. Franz Baader is co-editor of the highly-cited Description Logic Handbook and co-author of the first textbook on Description Logics, both published by Cambridge University Press. He has published more than 250 research articles in international conferences and journals. He is a fellow of the European Association for Artificial Intelligence (EurAI) since 2004 and a member of the Academia Europe since 2011.



Thomas Liebich, Dr.-Ing.

AEC3, buildingSmart, Germany

Title: OpenBIM. Quarter Century Development and Perspectives of the IFC standard

#### Biography:

Dr. Thomas Liebich holds a Diploma in Architecture and a PhD from the Bauhaus University Weimar. Over the last 10 years he worked actively on development and introduction of digital methods in design and construction with focus on Building Information Modeling, in particular on open BIM.

Thomas is managing partner of AEC3 Deutschland GmbH, a consulting firm delivering dedicated services for specifying and applying building information modeling methods and interoperability for the participants of construction projects. He is consulting government agencies, owners, operators, contractors and general designers on using BIM for collaborative work, including business process improvement.

Another focus of his professional life is standardization. He is leading the buildingSMART International team for developing the Industry Foundation Classes (IFC) since 1999. He is the convener of the ISO working group TC 59/SC 13/JWG 12 for data sharing in construction and of the European counterpart CEN/TC 442/WG 02 on Information Exchanges for BIM. In Germany he is the chairman of the DIN committee for BIM.

Major projects he carried out in his professional career include the world's first automatic code checking system in Singapore, the technical support for the first international architectural contest requiring openBIM - the National Museum in Oslo Norway, and the development of open BIM guidelines and validation process for the US Army Corps of Engineers in Germany. He is the co-author of the recent BIM Guide for Germany developed for the Federal Agency for Buildings, City Planning and Urban Affairs, contributed to the Road Map for Digital Design and Construction for the German Ministry of Transportation and Digital Infrastructure, BMVI, and is the co-lead for the scientific assessment of the first BIM pilots on infrastructure projects in Germany. He is part of the German BIM Consortia to support the BIM Roadmap 2020 and for the assessment of the 13 BIM pilots of Deutsche Bahn on behalf of BMVI.

He has been involved in many leading R&D projects, including the recent EU projects INTERLINK (object type library for road constructions). He consults the international IFC Rail project (China, France, Switzerland, Austria, Sweden, Finland) on data standards for railways (track, signal, communication and energy), including high-speed railways.

# PRESENTATION GUIDELINE

ECPPM 2021 September 15-17, 2021

Time Zone: UTC+2 (Central European Summer Time)

## Equipment needed:

1. A computer with an internet connection.
2. Headset with a microphone (recommended for optimal audio quality).
3. Webcam: built-in or USB plug-in.

## Environment requirement:

1. Quiet location
2. Stable internet connection
3. Proper lighting

## How to access the Zoom sessions:

1. The codes of the conference sessions and invitation links will be sent to your e-mail (provided in the registration form)
2. Enter code of the appropriate conference session or follow the link.

## Attention:

1. To control the time and avoid some unexpected situations, we advise you to record your presentation in advance as a backup. Each author has 15 minutes for presentation and 3 minutes for Q&A.
2. September 14, 2021 is for test presentation; please don't forget to test in order to guarantee the formal sessions go smoothly.
3. The conference is scheduled according to CEST time (UTC+2), please double check your test time and formal time to make sure that you will not miss the time.
4. The conference can be recorded; we will appreciate your proper behavior.

## Presentation recommendations:

Duration of presentation should be 15 minutes plus 3 minutes discussion. Possible structure is as follows:

1. Formulation of the problem: 3 min
2. Envisioned objective / result (what you want to achieve): 1 min
3. Applied method / new method / innovation / solution path: 5 min
4. Archived results (how good you achieved the envisioned objective; what are the limitations): 2 min
5. Example(s): 3 min
6. Conclusion: 1 min

Totally, these are 15 minutes, which should be provided with the proper number of slides so that 1 min = 1 PPT folio.

# PROGRAMME OVERVIEW

## Virtual ROOMS

Room A: plenary sessions, thematic sections in the left column of the program tables

Room B: thematic sections in right column of the program tables

Room C: EAPPM assembly meeting

All times are indicated in CEST (UTC+2)

Wednesday, 15<sup>th</sup> and Thursday, 16<sup>th</sup> of September

Time/Day	Wednesday, 15 <sup>th</sup> of September		Thursday, 16 <sup>th</sup> of September	
9:00-9:15	Registration			
9:15-10:45	Opening Prof. Vitaly Semenov, ISP RAS, Moscow Prof. Raimar Scherer, TU Dresden Plenary session  Philipp Nikandrov, GORPROJECT, Russia		Plenary session  Prof. Franz Baader, TU Dresden  Dr. Thomas Liebich, AEC3, buildingSmart, Germany	
10:45-11:00	Coffee break			
11:00-13:00	ICT impacts on BIM standardization and regulation	Models, methods, tools for design, engineering and construction (I)	Digital twins and cyber-physical systems (I)	Applications of artificial intelligence (I)
13:00-13:45	Lunch break			
13:45-15:45	Key aspects of data integration and management (I)	Models, methods, tools for design, engineering and construction (II)	Digital twins and cyber-physical systems (II)	Applications of artificial intelligence (II)
		City and building information modelling	Photogrammetry, laser scanning and point clouds	Organizational, perceptual and technological issues of BIM adoption (I)
15:45-16:00	Coffee break			
16:00-18:00	Key aspects of data integration and management (II)	BIM education and adoption	Environmental, social and economic dimensions of sustainability	Organizational, perceptual and technological issues of BIM adoption (II)
18:00-19:00	EAPPM Assembly Meeting		Closing Session	

## Wednesday, 15<sup>th</sup> of September

Time/Day	Wednesday, 15 <sup>th</sup> of September	
9:00-9:15	Zoom Registration	
9:15-10:45	<p>Opening Prof. Vitaly Semenov, ISP RAS, Moscow Prof. Raimar Scherer, TU Dresden</p> <p>Plenary session Philipp Nikandrov, GORPROJECT, Russia BIM-based design of megatall projects: Lakhta Center case</p> <p><i>Chair: Prof. Vera Galishnikova – Moscow State University of Civil Engineering, Russia</i></p>	
10:45-11:00	Coffee break	
11:00-13:00	<p>ICT impacts on BIM standardization and regulation <i>Chair: Prof. Robert Amor – University of Auckland, New Zealand</i></p>	<p>Models, methods, tools for design, engineering and construction (I) <i>Chair: Univ. Prof. Ardeshir Mahdavi – TU Wien, Austria</i></p>
11:00-11:20	<p>Digital description of the railway telecommunication system for a new data exchange format <i>Achraf Dsou, S. Karoui, J.D. Adounvo, P.E. Gautier, J.G. Philibert, C. Carpinteri, L. Lihai, L. Yifan &amp; M. Boutros</i></p>	<p>Archi-guide. Architect-friendly visualization assistance tool to compare and evaluate BIM-based design variants in early design phases using template-based methodology <i>K. Jaskula, Ata Zahedi &amp; F. Petzold</i></p>
11:20-11:40	<p>A critical analysis of linear placement in IFC models <i>Štefan Jaud, S. Esser, A. Borrmann, L. Wikstrom, S. Muhič &amp; J. Mirtschin</i></p>	<p>Polyhedral space partitioning as an alternative to component assembly <i>Vera Galishnikova &amp; W. Huhnt</i></p>
11:40-12:00	<p>IFC query language: leveraging power of EXPRESS and JSON <i>Sergey Morozov, S. Sazonov &amp; V. Semenov</i></p>	<p>A hierarchical kit library to support content reuse for mass customization <i>Jianpeng Cao &amp; D. M. Hall</i></p>
12:00-12:20	<p>DigiPLACE: Towards a reference architecture framework for digital platforms in the EU construction sector <i>Alexis David, A. Zarli, C. Mirarchi, N. Naville &amp; L. Perissich</i></p>	<p>Navigating the vast landscape of spatially valid renovation scenarios <i>A. Kamari, B. Li &amp; Carl Schultz</i></p>
12:20-12:40	<p>Using uncertainty to link compliance and creativity <i>Nicholas Nisbet</i></p>	<p>Towards semantic enrichment of early-design timber models for noise and vibration analysis <i>Camille Châteauvieux-Hellwig, J. Abualdenien &amp; A. Borrmann</i></p>
12:40-13:00	<p>Building permit process modeling <i>Judith Fauth</i></p>	<p>Approaching the human dimension of building performance via agent-based modeling <i>Christiane Berger &amp; A. Mahdavi</i></p>
13:00-13:45	Lunch break	
13:45-15:45	<p>Key aspects of data integration and management (I) <i>Chair: Prof. Jakob Beetz – RWTH University Aachen, Germany</i></p>	<p>Models, methods, tools for design, engineering and construction (II) City and building information modelling <i>Chair: Dr. Pieter Pauwels – Eindhoven University of Technology, the Netherlands</i></p>
13:45-14:05	<p>Towards conceptual interoperability of BIM applications: transaction management versus data exchange <i>Vitaly Semenov, S. Arishin &amp; G. Semenov</i></p>	<p>Requirements analysis for a project-related quality management system in the construction execution <i>Sebastian Seiß &amp; H.-J. Bargstädt</i></p>
14:05-14:25	<p>A system architecture ensuring consistency among distributed, heterogeneous information models for civil infrastructure projects <i>Sebastian Esser &amp; A. Borrmann</i></p>	<p>BIM-based cost estimation in a road project – proof of concept and practice <i>David Fürstenberg, T. Gulichsen, O. Lædre &amp; E. Hjelseth</i></p>
14:25-14:45	<p>A framework for leveraging semantic interoperability between BIM applications <i>Michael Belsky</i></p>	<p>A new approach for delay analysis process <i>Attila Dikbas &amp; Can Durmus</i></p>
14:45-15:05	<p>Evaluating SPARQL-based model checking: potentials and limitations <i>André Hoffmann, M. Shi, A. Wagner, C.-D. Thiele, T.-J. Huyeng, U. Rüppel &amp; W. Sprenger</i></p>	<p>A trend review on BIM applications for smart cities <i>Aritra Pal &amp; S.H. Hsieh</i></p>
15:05-15:25	<p>A BIM to BEM approach for data exchange: advantages and weaknesses for industrial buildings energy assessment <i>Matteo Del Giudice, M. Dettori, S. Magnano &amp; A. Osello</i></p>	<p>Matching geometry standards for geospatial and product data <i>Helga Tauscher</i></p>
15:25-15:45	<p>Microservice system architecture for data exchange in AEC industry <i>Goran Šibenik, I. Kovacic, T.-J. Huyeng, C.-D. Thiele &amp; W. Sprenger</i></p>	<p>City and building information modelling using IFC standard <i>V. Shutkin, N. Morozkin, Vladislav Zolotov &amp; V. Semenov</i></p>
15:45-16:00	Coffee break	

## Wednesday, 15<sup>th</sup> of September

15:45-16:00	Coffee break	
16:00-18:00	Key aspects of data integration and management (II) <i>Chair: Dr. Alain Zarli – R2M Solution, France</i>	BIM education and adoption <i>Chair: Prof. Boyan Georgiev – University of Architecture, Civil Engineering and Geodesy, Bulgaria</i>
16:00-16:20	Occupant-centric ontology as a bridge between domain knowledge and computational applications <i>Ardeshir Mahdavi, V. Bochukova &amp; C. Berger</i>	Experiences from large scale VDC-education in Norway <i>Eilif Hjelseth &amp; M. Fischer</i>
16:20-16:40	Application of ontologically streamlined data for building performance analysis <i>Dawid Wolosiuk &amp; A. Mahdavi</i>	Analysis of digital education in construction management degree programs in Germany and development of a training model for BIM teaching <i>Marianne Pieper, S. Seiß &amp; A. Nast</i>
16:40-17:00	Interlinking geometric and semantic information for an automated structural analysis of buildings using semantic web <i>Tim-Jonathan Huyeng, C.-D. Thiele, A. Wagner, M. Shi, A. Hoffmann, U. Rüppel &amp; W. Sprenger</i>	Analysis of the influencing factors for the practical application of BIM in combination with AI in Germany <i>Anna Nast &amp; A. Doroschkin</i>
17:00-17:20	Analysis of design phase processes with BIM for blockchain implementation <i>Marijana Srečković, G. Šibenik, D. Breitfuß, T. Preindl &amp; W. Kastner</i>	The practice of VDC framework as a performance measurement system for projects <i>Saad B.S. Ahmad &amp; E. Hjelseth</i>
17:20-17:40	Digital traceability for planning processes <i>Dominik Breitfuss, G. Šibenik &amp; M. Srečković</i>	Practical experiences from initiating development of machine learning in a consulting engineering company <i>Torkild Alstad &amp; E. Hjelseth</i>
17:40-18:00		Applying activity theory to get increased understanding of collaboration within the VDC framework <i>E. Hjelseth &amp; Sujesh Sujan</i>
18:00-19:00	EAPPM Assembly Meeting <i>Chair: Prof. Raimar Scherer</i>	

Thursday, 16<sup>th</sup> of September

Thursday, 16 <sup>th</sup> of September		
9:00-10:45	<p>Plenary session</p> <p>Prof. Franz Baader, TU Dresden A Description Logic journey</p> <p>Dr. Thomas Liebich, AEC3, buildingSmart, Germany OpenBIM. Quarter century development and perspectives of IFC standard</p> <p><i>Chair: Dr. Ana Roxin – University of Bourgogne Franche-Comté, France</i></p>	
10:45-11:00	Coffee break	
11:00-13:00	<p>Digital twins and cyber-physical systems (I)</p> <p><i>Chair: Dr. Helga Tauscher – Dresden University of Applied Sciences, Germany</i></p>	<p>Applications of artificial intelligence (I)</p> <p><i>Chair: Prof. Adam Borkowski. – Institute of Fundamental Technological Research, Polish Academy of Sciences, Poland</i></p>
11:00-11:20	<p>A cyber physical system for dynamic production adaptation</p> <p><i>Michael Polter, P. Katranuschkov &amp; R.J. Scherer</i></p>	<p>Defeasible reasoning for automated building code compliance checking</p> <p><i>Beidi Li, C. Schultz, J. Dimyadi &amp; R. Amor</i></p>
11:20-11:40	<p>A Digital Twin factory for construction</p> <p><i>Calin Boje, S. Kubicki, A. Zarli &amp; Y. Rezgui</i></p>	<p>Metadata based multi-class text classification in engineering project platform</p> <p><i>Meiling Shi, A. Hoffmann &amp; U. Rüppel</i></p>
11:40-12:00	<p>A framework for development and integration of digital twins in construction</p> <p><i>Alessandra Corneli, B. Naticchia, A. Carbonari &amp; M. Vaccarini</i></p>	<p>Using Topic Modeling to restructure the archive system of the German Waterways and Shipping Administration</p> <p><i>André Hoffmann, M. Shi &amp; U. Rüppel</i></p>
12:00-12:20	<p>Digital Twin as a framework for a machine learning based predictive maintenance system</p> <p><i>Christian-Dominik Thiele, J. Brötzmann, T.-J. Huyeng, U. Rüppel, S. R. Lorenzen, H. Berthold &amp; J. Schneider</i></p>	<p>Applying weak supervision to classify scarce labeled technical documents</p> <p><i>Meiling Shi, A. Hoffmann &amp; U. Rüppel</i></p>
12:20-12:40	<p>Lifecycle oriented digital twin approach for prefabricated concrete modules</p> <p><i>M. Wolf, Oliver Vogt, J. Huxoll, D. Gerhard, Simon Kosse &amp; M. König</i></p>	<p>An overview of data mining application for structural damage detection in the last decade (2009 – 2019)</p> <p><i>Fangzheng Lin, J. Liu &amp; R.J. Scherer</i></p>
12:40-13:00		<p>Assumption of undetected construction damages by utilizing description logic and fuzzy set theory in a semantic web environment</p> <p><i>Al-Hakam Hamdan &amp; R.J. Scherer</i></p>
13:00-13:45	Lunch break	
13:45-15:45	<p>Digital twins and cyber-physical systems (II)</p> <p>Photogrammetry, laser scanning and point clouds</p> <p><i>Chair: Dr. Dimitrios Rovas – University College London, UK</i></p>	<p>Applications of artificial intelligence (II)</p> <p>Organizational, perceptual and technological issues of BIM adoption (I)</p> <p><i>Chair: Prof. Žiga Turk – University of Ljubljana, Slovenia</i></p>
13:45-14:05	<p>Semantic contextualization of BAS data points for scalable HVAC monitoring</p> <p><i>Ville Kukkonen</i></p>	<p>An AI-based approach for automated work progress estimation from construction activities using abductive reasoning</p> <p><i>Karsten Johansen, R. O. Nielsen, J. Teizer &amp; C. Schultz</i></p>
14:05-14:25	<p>Integrating sensor- and building data flows: a case study of the IEQ of an office building in the Netherlands</p> <p><i>S. van Gool, Dajuan Yang &amp; P. Pauwels</i></p>	<p>METIS-GAN: An approach to generate spatial configurations using deep learning and semantic building models</p> <p><i>Hardik Arora, C. Langenhan, F. Petzold, V. Eisenstadt &amp; K.-D. Althoff</i></p>
14:25-14:45	<p>Combining point-cloud-to-model-comparison with image recognition to automate progress monitoring in road construction</p> <p><i>Andreas Ellinger, C. Wörner, T. Walther &amp; P. Vala</i></p>	<p>“We need better software” – the users’ perception of BIM</p> <p><i>Anders Rekve &amp; E. Hjelseth</i></p>
14:45-15:05	<p>The use of the BIM-model and scanning in quality assurance of bridge constructions</p> <p><i>Christian Nordahl Rolfsen, H. Hosamo, A.K. Lassen, D. Han &amp; C. Ying</i></p>	<p>Development needs on the way to information-efficient BIM-based supply chain management of prefabricated engineer-to-order structures</p> <p><i>P. Lahdenperä, Markku Kiviniemi, R. Lavikka &amp; A. Peltokorpi</i></p>
15:05-15:25	<p>Application of railway topology for the automated generation of geometric digital twins of railway masts</p> <p><i>M.R. Mahendrini Fernando Ariyachandra &amp; I. Brilakis</i></p>	<p>A systematic review of project management information systems for heavy civil construction projects</p> <p><i>Wenjun Chen, M. Leon &amp; P. Benton</i></p>
15:25-15:45		<p>BIM model uses through BIM methodology standardization</p> <p><i>A. Barbero, M. Del Giudice, Francesca Maria Ugliotti &amp; A. Osello</i></p>
15:45-16:00	Coffee break	

Thursday, 16<sup>th</sup> of September

15:45-16:00	Coffee break	
16:00-18:00	<p>Environmental, social and economic dimensions of sustainability  <i>Chair: Prof. Attila Dikbaş – İstanbul Teknik Üniversitesi, Turkey</i></p>	<p>Organizational, perceptual and technological issues of BIM adoption (II)  <i>Chair: Prof. Eilif Hjelseth – Norwegian University of Science and Technology, Norway</i></p>
16:00-16:20	<p>From linear to circular: Circular Economy in the Danish construction industry  <i>T.S. Rasmussen, Ricardo Esclusa, E. Petrova &amp; K.D. Bohnstedt</i></p>	<p>Housing energy-efficient renovation adoption and diffusion: a conceptual model for household decision-making process  <i>Hua Du, Q. Han &amp; B. de Vries</i></p>
16:20-16:40	<p>A BIM-based tool for the environmental and economic assessment of materials in a building within early design stages  <i>Q. Han, Nuo Zhang &amp; C.D. Van Oeveren</i></p>	<p>Multi-stakeholder involvement in construction and challenges of BIM implementation  <i>Zeynep Yazicioğlu</i></p>
16:40-17:00	<p>Digital technologies as a catalyst to elevating IPD+BIM synergy in sustainable renovation of heritage buildings  <i>Bani Feriel Brahmi, S. Sassi-Boudemagh, I. Kitouni &amp; A. Kamari</i></p>	<p>Impacts of BIM Implementation on construction management processes in Turkey  <i>Yigit Beslioglu &amp; İ. Akyaz</i></p>
17:00-17:20	<p>Evaluating the concept and value of smart buildings for the development of a smarter procurement strategy  <i>J. Olsen &amp; Jan Karlshøj</i></p>	<p>Building information modeling warnings towards a deadline  <i>Lasse Damhus, P. N. Gade &amp; R. Qian</i></p>
17:20-17:40	<p>A conceptual method for data-driven analysis of project process and context to study collaboration            A conceptual method to compare projects by combining assessment of controllable and non-controllable factors  <i>Sujesh Sujan &amp; E. Hjelseth</i></p>	<p>The role of trust in the adoption of BIM-systems  <i>Peter Nørkjær Gade, J. de Godoy &amp; K. Otrell-Cass</i></p>
17:40-18:00	<p>Exploring the degree of automated process metrics in construction management  <i>Kamalan Rashasingham &amp; E. Hjelseth</i></p>	
18:00-19:00	<p>Closing Session  <i>Chairs: Prof. Vitaly Semenov &amp; Prof. Raimar Scherer</i></p>	

# BOOK OF ABSTRACTS

ICT IMPACTS on BIM STANDARDIZATION,  
REGULATION POLICY and LEGISLATIVE PROCESSES

## Digital description of the railway telecommunication system for a new data exchange format

*A. Dsoul, S. Karoui, J.D. Adounvo, P.E. Gautier & J.G. Philibert*

French National Railway Company, Paris, France

*C. Carpinteri*

Rete Ferroviaria Italiana, Rome, Italy

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*M. Boutros*

Egis Rail, Paris, France

**ABSTRACT:** Building Information Modeling (BIM) represents a new approach to manage construction facilities throughout their lifecycle by providing a collaborative platform where building information models can be shared in a 3D digitalized environment. However, the BIM processes are based on fragmented information systems that are disparate and do not allow information exchange among the different software platforms inside the BIM ecosystem. This represents a real challenge for the railway operators and stakeholders who become more and more interested in implementing BIM into their business processes. The scope of this research includes, therefore, a digital description of the telecommunication railway system as part of the IFC Rail project that aims to tackle the interoperability issue in the railway domain by extending Industry Foundation Classes schema, which is an ISO open international standard for data sharing in the building industry, to include the data schema of railway assets as part of the IFC5 release.

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## A critical analysis of linear placement in IFC models

*Š. Jaud, S. Esser & A. Borrmann*

Chair of Computational Modelling and Simulation, Technical University of Munich, Munich, Germany

*L. Wikström*

Triona SE, Stockholm, Sweden

*S. Muhič*

buildingSMART International Ltd, Kings Langley, Hertfordshire, UK

*J. Mirtschin*

Geometry Gym Pty Ltd., Port Fairy, Australia

**ABSTRACT:** The open data exchange standard Industry Foundation Classes (IFC) has been recently significantly extended to also cover infrastructure facilities such as roads and railways. The results of these activities form part of version 4.3 of the standard. Linear placement of objects is one of the most important concepts in infrastructure asset modelling. As such, Release Candidate 1 of IFC 4.3 has been critically analysed. In this paper, we address several issues that were identified together with the participants of the IFC Infrastructure Extension

Deployment and IFC Rail Phase 2 projects. We present an improved model removing unnecessary doubling of concepts and reusing many already established entities. We showcase the new model on two example scenarios from one of the projects and determine better adherence with the IFC legacy. The proposed improvements have been adopted in Release Candidate 2 of the IFC 4.3

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## [IFC query language: leveraging power of EXPRESS and JSON](#)

*S. Morozov*

Ivannikov Institute for System Programming of the Russian Academy of Sciences,  
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M.V. Lomonosov Moscow State University, Russia

*S. Sazonov*

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Moscow Institute of Physics and Technology, Dolgoprudny, Russia

Higher School of Economics, Moscow, Russia

**ABSTRACT:** Recently, Building Information Modeling (BIM) technologies and, in particular, BIM servers proceeding with IFC-driven product data have become increasingly important in architecture, engineering and construction (AEC). However, a standard query language for IFC data has not yet been established, which prevents the interoperability between BIM applications and wider adoption of the IFC standard. In the paper requirements to an IFC query language are summarized with the focus on the compliance and harmonization with data definition and data manipulation languages which generally are the parts of a common data access interface. As a result of the study, the IFC query language was proposed and formalized. Using EXPRESS constructs and JSON structures, the language allows to specify complex predicative queries on object collections and recursive traversing queries on object networks. Explanatory examples of typical IFC queries are provided to illustrate the proposed language and prove its advantages.

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## [DigiPLACE: Towards a reference architecture framework for digital platforms in the EU construction sector](#)

*A. David & A. Zarli*

ECTP, Brussels, Belgium

*C. Mirarchi*

Politecnico di Milano, Milan, Italy

*N. Naville*

CSTB, Marne-la-Vallée, France

*L. Perissich*

Federcostruzioni, Roma, Italy

**ABSTRACT:** With the increase of digitalisation and the spread of digital tools and applications, the Construction sector faces a need for digital platforms and hubs that should allow the development and generalisation of common digital services and data for all stakeholders of the value chain, in all phases of Construction processes. These digital platforms should provide a fluent communication of semantic data models and instances between computer-based systems, a seamless integration of 3rd-party services and ensure a secured data management, based on agreed standards. The H2020 DigiPLACE project aims at devising a European-level consensus on a Reference Architecture Framework for Construction digital platforms and a roadmap for future rapid deployment and use. This paper introduces its preliminary results, namely an inventory and evaluation of existing digital platforms used in the Construction sector and selected other industrial sectors, the identification of success factors and key expected characteristics of such digital platforms functionalities.

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### Using uncertainty to link compliance and creativity

*N. Nisbet*

AEC3 UK Ltd, UK

**ABSTRACT:** Compliance to regulations, requirements and recommendations remains a weak point for the design, construction, and operation in the built environment. The RASE mark-up methodology has been demonstrated to significantly raise the accuracy and efficiency of the capture and evaluation of regulations and requirements. This paper extends the relevance of RASE beyond regulations and requirements into two new areas, firstly where uncertainty may impact decision making and secondly where design is supported by constraints. Examples are taken from UK Building Regulations Approved Documents Part M on Accessibility.

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### BIM model uses through BIM methodology standardization

*A. Barbero, M. Del Giudice, F.M. Ugliotti & A. Osello*

Politecnico di Torino, Turin, Italy

**ABSTRACT:** Digital transformation is influencing the strategy to develop virtual repository able to collect data from different disciplines and domains in a useful way for the building lifecycle. In this framework, Building Information Modelling (BIM) can be the innovative methodology to optimize the overall workflow including a proper definition and management of geometrical and alphanumeric contents. The article aims to investigate the meaning of standard according to specific model uses that goes through the identification of the owner's objectives and their

operational declination by means of a defined protocol of activities and tailor-made solutions. The study presents a progressive increasing of the complexity of the BIM system, which, starting from the definition of an As-is model, is enriched through the integration with other data domains and improves its usability through customized virtual experiences.

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## Building permit process modeling

*J. Fauth*

Bauhaus University, Weimar, Germany

**ABSTRACT:** To implement BIM models successfully in an established procedural environment it is necessary to understand the current state of processes and their influences. Significant decisions are necessary until building permitability is determined. Automated model checking can only help with a certain number of regulations, which have quantitative content with measurable parameters. Regulations containing qualitative content still require manual reviewing by the authority. Detailed processes regarding decision making are currently not investigated or published. Building permit processes differ even within the authorities of a state or a country and have been mostly developed traditionally. A decision model is proposed as a decision-supporting instrument which shows the authorities' reviewer possibilities and alternatives of actions during a building permit review. This procedure aims at more transparency and objectivity. The proposed approach provides a starting point for implementing and using BIM. It also serves as a basis for further research in an international context of standardization of building permitting.

# KEY ASPECTS of DATA INTEGRATION and MANAGEMENT

## Towards conceptual interoperability of BIM applications: Transaction management versus data exchange

*V. Semenov*

Ivannikov Institute for System Programming of the Russian Academy of Sciences, Moscow, Russia

Moscow Institute of Physics and Technology, Dolgoprudny, Russia

Higher School of Economics, Moscow, Russia

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**ABSTRACT:** Building information modelling (BIM) originates as an innovative methodological approach to enhance products, processes and to reach greater efficiencies in the architecture, engineering, construction and facility management industry. Although BIMtools have been successfully adopted, their integrated use encounters numerous software interoperability issues. In the paper, these issues are examined by addressing to the conceptual multi-level interoperability model. The presented data exchange scenarios explain why the expectations from the use of open BIM standards and Industry Foundation Classes (IFC) have not yet fully met. As a result, the requirements for an interface to access IFC-driven data are formulated. The interface provides project, revision and transaction management methods that allow the synchronization of data rather than the direct exchange of IFC files. The correct implementation and use of the interface by software vendors could predetermine a commonly accepted way from technically interoperable applications to substantively interoperable IFC-compliant integrated systems.

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## A system architecture ensuring consistency among distributed, heterogeneous information models for civil infrastructure projects

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**ABSTRACT:** The application of suitable data structures is an essential aspect for novel digital workflows in engineering and design processes of the Architectural, Engineering, and Construction (AEC) industry. Since model-based data exchange gets increasingly adopted by the industry, feasible and more effective methods must be considered to improve data exchange in the future. While the concept of federated model integration and container-based collaboration as demanded by ISO19650 is well established and widely adopted, it shows a number of deficiencies, in particular when it comes to consistency preservation across the domain models and the handling of design updates. Current practice relies on the exchange of complete domain models which requires the manual identification of design changes by all

other stakeholders. Consistency is checked merely by collision detection, which however can cover only geometric aspects. To overcome these limitations, this paper proposes a comprehensive system architecture as well as techniques to identify updates in models and federate such update information by means of update patches. To this end, specific focus is put on possible mechanisms to detect changes and to integrate update patches in the receiving application.

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## A framework for leveraging semantic interoperability between BIM applications

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**ABSTRACT:** AEC/FM industry experiences significant challenges in full adoption of BIM despite its obvious benefits. Deficient semantic interoperability between BIM applications is one of the factors causing the industry dissatisfaction. The IFC schema is the open, international, vendor agnostic standard for data exchanges between BIM applications. It is a generic, rich and flexible standardized data model. However, the IFC specification lacks formal rigidity to unambiguously capture the full semantics needed for seamless and reliable information exchanges. A framework for new approach to overcome that drawback and improve the overall semantic interoperability is outlined in the paper. The novelty of the approach is that it places the onus for interpretation of exchanged data on an importing application which is an opposite to current practices when an exporting application is responsible for a semantic content of IFC exchange file. A pilot technical implementation was developed to test the applicability of the approach.

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## Towards semantic enrichment of early-design timber models for noise and vibration analysis

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**ABSTRACT:** Low carbon footprint and high sustainability characterize timber construction. Accordingly, architects and engineers are increasingly using it in their designs. However, a major challenge in timber construction is to provide a sufficient sound insulation. In contrast to masonry and concrete construction, timber construction lacks software tools to evaluate sound insulation and usability with regard to vibrations. Using Building Information Modelling (BIM), the design phases already incorporate model-based calculations for sound insulation prognosis. However, performing such evaluations requires specific information that describes the junctions between elements. For example, relevant factors are: the type of elements in the junction, the connecting elements like screws or angle brackets, and the decoupling materials

used. Typically the building information model lacks this information; hence, we present a semantic enrichment approach overcoming these limitations.

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## Evaluating SPARQL-based model checking: potentials and limitations

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Zentrale Technik, Digitalisierung & Softwareengineering (DS) · Digitalization & Software Engineering BIM 5D®, Ed. Züblin AG, Germany

**ABSTRACT:** Model checking is an important task in the BIM collaboration process to prevent expensive planning errors. The submodels of the individual disciplines are transferred into a coordination model. Part of the transfer is a conversion into an exchange format. The exchange format allows the import into the model checking application. In the model checking application routines are performed to check the model against collisions and building regulation violations. During the transfer into the exchange format, information may get lost, especially with parameters that are not yet part of the exchange format supported by the authoring software. In recent years, ontologies have been investigated as a feasible approach to combine the submodels, since they model data in a flexible manner. Hence in the conversion process to an application-specific ontology, the data structure of the submodels can widely persist, which could lead to smaller information loss in comparison to converting the data into a standardized exchange format. The evaluation of the geometric properties of the building is indispensable for detecting and analyzing collisions. The basis for the connection of the different submodels could be the BOT (Building Topology Ontology), which defines the topological structure of a building and can be used to represent further building information by linking it with other ontologies. The relevant geometric relationships for the collision model checks have to be derived with a geometry kernel. For the research in this paper pythonOCC, a wrapper for the geometry kernel Open CASCADE is used with the Semantic Web's own query language SPARQL, queries can be formulated to analyze the collision relationships in combination with other semantic information. These queries can be used to verify model correctness. By connecting the information from different domains, more sophisticated tests are possible than in an exchange format dependent model checking application. The goal is to integrate the developed functionalities into a project platform. This platform is based on an extensive project description in an ontology-based data model and is connected to different authoring tools for the exchange of information.

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## Interlinking geometric and semantic information for an automated structural analysis of buildings using semantic web

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**ABSTRACT:** The advancing digitization in the building industry highlights weak points in the digital infrastructure. Due to heterogeneous software landscapes, cross-application data exchange is a frequently criticized process in particular, for which no satisfying solution exists so far. Open and application-independent data formats are necessary and therefore the current research project SCOPE focuses on developing such formats by applying Semantic Web Technologies. This article proposes an approach that enriches a graph with relevant information for structural design and provides the enhanced description as a calculation basis for structural analysis software. A novel ontology, the TDY-Ontology, is designed to connect geometry descriptions with structural specific semantic information, like the standard of the analysis to be executed, bearing arrangements, bedding of floor slabs or the definition of joints and loads.

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### [A BIM to BEM approach for data exchange: advantages and weaknesses for industrial buildings energy assessment](#)

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**ABSTRACT:** Energy assessment has become an important and argued topic in recent years due to climate changes. For this reason, the building industry is crossing a digital transition period. In this context, the development of 3D parametric models as a digital twin is due to the energy assessment of private and public buildings. The purpose of this study is to analyze Building Information Model to Building Energy Model process, with an essential focus on data transfer, which plays a key role to maintain all the information required for energy simulations. Starting from the evaluation of the most used standard exchange formats for energy simulation, this contribution highlights the challenges that occur during the export/import process finding out the lack of data that make the process not error-free. The selected case studies allowed to test the proposed process and analyze the main steps for building energy simulation.

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### [Occupant-centric ontology as a bridge between domain knowledge and computational applications](#)

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**ABSTRACT:** In the past, building information modeling (BIM) in general and building performance simulation (BPS) in particular have developed and deployed fairly detailed representations of building geometry, fabric, construction, and technology. Relatively less

attention has been paid to the representations of building users. Thereby, one of the key challenges concerns the matching between the nature and level of building-related performance queries on the one hand and the required or appropriate resolution of applied occupant models. This paper addressed this challenge via a two-fold path: A “top-down” path examines the ontological scope of comprehensive, theory-driven representations of building occupants. Such representations could be presumably condensed so as to match the informational requirements of specific performance queries. On the other hand, a “bottom-up” path involves the reverse-engineering of typical building performance simulation tools, focusing thereby on the implicit schema rooted in the tool’s input modalities vis-à-vis occupant information. The top-down path can inform the definition of a common schema for occupant-related information. The bottom-up reverse engineering can provide a reality check in view of the ontological depth of common occupant representations in analysis tools. The pursuit of these paths is suggested to highlight a gap between behavioral domain knowledge and default occupant representation in BIM and the analysis of this gap can facilitate the derivation of related ontologies.

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## Application of ontologically streamlined data for building performance analysis

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**ABSTRACT:** Buildings are increasingly equipped with data monitoring infrastructures to collect multiple layers of dynamic data pertaining to the states and events related to systems’ performance, indoor-environmental conditions, occupants’ location, movement, and control-oriented actions representation of dynamic building related data. Efficiently utilized, this data could not only enhance the quality and effectiveness of buildings’ operational regimes, but also enrich the knowledge base for building design decision support. However, to exploit the potential of this data effectively, seamless data transformation processes are needed, starting from raw monitoring data and ending in adequately structured and visualized building performance data. In the present contribution, we provide a detailed blueprint of a well-defined and ontologically supported instance of such a transformation process. To illustrate this process, we focus in this paper on a specific class of building performance queries that require information on buildings’ visually relevant boundary conditions. Such queries pertain to, for example, the intensity of incident solar radiation of buildings’ envelope components, the daylight availability and distribution in interior spaces, and the expected output of building-integrated solar energy harvesting systems.

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## Microservice system architecture for data exchange in the AEC industry

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**ABSTRACT:** Realization of inter-domain model-based data exchange in the AEC industry has not yet managed to fully satisfy the end user's needs. While microservices are getting more present on the market, its application for the data exchange in the building planning process has not been considered. This paper investigates the potential of microservices in realizing the data exchange within planning and construction. System architecture of an existing monolithic software tool is converted to a microservice system architecture with the help of literature review, analysis of Docker system and expert knowledge. The results show multiple possibilities to containerize a monolithic application with diverse advantages, differing in effort to be containerized. While the microservices do not offer a smooth transition of system architectures from the existing data exchange solutions, containerization offers the flexibility for non-standardized processes which could be tailor-made organized and easily replaced. Although the orchestration between the services is not easy to achieve and the implementation requires significant effort and a paradigm shift in the planning process, the advantages of microservices can already be used in the data exchange process.

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[Analysis of design phase processes with BIM for blockchain implementation](#)

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**ABSTRACT:** The increasing digitalization and thus evidently advancing change in the architecture, engineering and construction (AEC) industry, requires new business models, processes and strategies. Blockchain (BC), smart contracts and decentralized applications (DApps) are still underused in AEC. BC and its potential of inclusion into the communication between project stakeholders has shown that it is not just a technology that is ready to use, but requires a thorough insight into the design process of domain-specific stakeholders, their interests and their collaboration workflows for a holistic Building Information Modeling (BIM) and BC-supported solution for the design phase. This paper introduces process modeling of BIM-workflows in the design phase. We propose a conceptual framework for the implementation of a design process with BC based on the integration of three underlying theories: design theory, configuration theory and task-technology fit. The main assumption is, before we can capture processes (1) we need to understand them (design theory) in order to re-engineer them for distributed ledger technologies (DLT) (2) we need to adapt them to

changing requirements (configuration theory), and finally (3) continually re-adjust Information Technology (IT) and processes interdependence (task-technology fit).

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## Digital traceability for planning processes

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**ABSTRACT:** The increasing complexity of communication and collaboration processes due to the use of building data models and object-based change management, create the need for efficient ways of transparency and traceability within planning processes. The growing presence of BIM (Building Information Modelling) digitalises the AEC industry and produces numerous assets in digital form, but their added value is not completely exploited. Blockchain (BC) and Smart Contracts (SC) might deliver improvement to communication and collaboration in the design phase. Based on a framework for assessing BIM based workflows, processes are analysed according to three sub-categories: project-stakeholder involvement, data-flow and single actions, which form a process-flow. The information gained with the application of this framework, grounded in a use case, is further explored in a conceptual model for SCs in the design phase of a building project. The focus hereby lies on existing processes which can be translated into a SC, and not on the alternation of currently applied workflows. SCs will be used as a tool, for supporting mandatory actions by each project stakeholder and to create a digital reference of changes in a BIM model on a BC.

MODELS, METHODS and TOOLS for DESIGN,  
ENGINEERING, CONSTRUCTION and MAINTENANCE

## Polyhedral space partitioning as an alternative to component assembly

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**ABSTRACT:** Building information models are conventionally assembled from individually constructed components. For communication and collaboration, data are mapped to the model using standards like the Industry Foundation Classes (IFC). The specification of the topology of a component is shape-dependent. Interoperability of software systems of different vendors has not been achieved with the IFC concept. Polyhedral space partitioning is proposed as an alternate approach to the solution of the interoperability problem. Some fundamental features of the approach are presented in this paper. Unbounded space is partitioned by splitting one component at a time. Polygons and dihedral cycles suffice to model the topology. Collisions and gaps are detected by testing only the component that is being split. Handling of the geometric user surface is simple because the topology is treated by a hidden core model. The model structure supports semantic expansion for physical, functional, economic, social, administrative and other applications.

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## A hierarchical kit library to support content reuse for mass customization

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**ABSTRACT:** Design reuse is an approach to achieve product variety while keeping the low cost and high efficiency of product development found in mass customization. Kit library is an application of virtual prototype reuse. Based on the object-oriented modeling, a framework of hierarchical kit library is proposed. The category, representation and approaches to customize the library content is illustrated in the context of hybrid industrialized construction. The process of hierarchy construction is given to connect the distributed library resources from spatial layout, structural modules and production parts respectively. The strategy facilitates a wider scope of customer-driven design by providing building kits that can support end-to-end building configuration, rather than traditional client participation at a single phase of the project.

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## Archi-guide. Architect-friendly visualization assistance tool to compare and evaluate BIM-based design variants in early design phases using template-based methodology

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**ABSTRACT:** Most of the Building Performance Simulation (BPS) tools are rarely used by architects as they are considered as too complex and cumbersome, as they are not compatible with architects' needs (Attia et al. 2009). The goal of this work was to develop an architect-friendly template-based assessment tool for variant evaluation in early design phases. Based on a literature review, both qualitative and quantitative criteria were selected and simplified into three categories: social, economic and environmental factors. The main objectives for developing the tool were user-friendliness, flexibility and integration of a knowledge base. As proof of concept, a visualization tool called Archi-guide was put forward and tested with a sample project. The tool includes multiple panels giving freedom in terms of exploring the building variants' data. In the end, the tool was evaluated in an online user study by architects and architecture students.

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## Navigating the vast landscape of spatially valid renovation scenarios

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**ABSTRACT:** Renovation, as a design task, can be defined so as to change building elements – repair, replace, add, remove, refurbish – in order to meet a set of given performance criteria (key performance indicators, KPIs). As a search and optimization task, the set of all ways that a building can be changed to maximize performance criteria is enormous. The aim of this paper is to present a new approach, and prototype search engine, that enables designers to explore aspects of geometric and spatial changes to a building under renovation in addition to a large variety of non-geometric renovation options, e.g. adjusting the dimensions and positions of windows. Our new renovation scenario search engine automatically identifies spatial inconsistencies, such as: windows stretching so far that they overlap each other or go beyond the embedding wall; added walls physically intersecting (clash detection), etc. We evaluate our method and prototype system on a large scale residential building in Denmark.

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## Approaching the human dimension of building performance via agent-based modeling

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**ABSTRACT:** This paper provides an overview of recent research efforts regarding the application of agent-based modeling (ABM) of building occupants in the context of buildings' energy and indoor-environmental performance assessment. Toward this end, we focus on the methods used in ABM for the representation of occupants' behavior and their environment. Our review suggests that occupant-centric ABM applications frequently rely on sparse domain knowledge and limited theoretical foundations. The representations of the built environment, on the other hand, involve lesser challenges. With regard to coupling techniques (between models of occupants and models of environment), there is a lack of consistent and scalable approaches.

However, the main challenge of ABM lies in the paucity of empirically-validated knowledge concerning processes related to occupants' perception, evaluation, and behavior. Future research must thus pursue broad collaborative efforts to collect and utilize observational data from both field and laboratory studies of occupants' requirements, attitudes, and behavior.

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### [BIM-based cost estimation in a road project – proof of concept and practice](#)

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**ABSTRACT:** Digital transformation can improve productivity and reduce uncertainty in AEC projects. BIM-based workflows play an important role in this transformation. The IFC format has emerged as exchange standard in road projects and allows BIM to be exported from design software to cost estimation software. Therefore, we tested a workflow in a real-life road project from Norway. We show how BIM-based cost estimation can be made with commercial software and uncover related challenges. We used a Design Science Research approach and developed an artefact in the form of an IFC based link between design and cost estimation software. IFC entities were expanded with coded properties based on standard specification texts. We concluded that BIM-based cost estimation improves productivity, reduces uncertainty and eliminates random human errors by automating repetitive and time-consuming tasks. Further research with different software and specification systems in more countries are necessary.

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### [Automatic detection of construction risks](#)

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**ABSTRACT:** Risk detection and allocation becomes increasingly important to successful project delivery. This is particularly true for mega infrastructure projects, where technical and institutional complexity increases the risk and challenges for collaboration. While early studies developed various methods and tools for risk detection and allocation, industry practice remains experience-based and focuses on opinions and discussions from subject matter experts. This paper will examine the effectiveness of existing methods to identify construction risks and then presents a novel approach to risk detection using case based reasoning and text mining techniques. The method is built on a large project risk database and features semantic inquiry and automatic generation of risk register according to specific project characteristics. I-

495/270 managed lanes project from the state of Maryland will be used to demonstrate the process of automatic risk detection.

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## Optimization method for choosing a set of means for probability of failure reduction of critical infrastructures

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**ABSTRACT:** Various measures can be implemented to improve mechanical system reliability. Choosing the optimal set of measures is a difficult task. It can be solved in three steps : forming a full set of possible combinations of safety measures, assessing the reliability increment increase and the cost of each combination of sets; selecting the champion set (the maximal reliability increase), or by optimization. The main difficulty in posing such a problem is in describing how each of the used safety module interacts with the protected system; assessing what reliability increase will the safety means deliver (its cost known as an initial data), for a specific potentially dangerous object of known configuration, in the context of a specific incident scenario or normal operation. This paper describes a new universal matrix-based algorithm that solves the increment increase reliability problem due to the implementation of the safety means for complex systems.

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## A new approach for delay analysis process

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**ABSTRACT:** Float time is defined as a delay of early start activities, which is not causing a delay of the entire project. Nowadays, one of the most unknown answer around the construction sector is who owns the float and how can it be used. Especially, during large scale and complicated projects, reckless usage of float times by the name of ‘first come first served’, causes unexpected disputes as a result of change of the critical path. In this study parameters of delays such as float concepts were stated. Relations between float usage and delay analysis types were investigated through an example. Importance of an objective float sharing was emphasized due to giving confidence to parties by avoiding leaving an open field that will cause conflict between them. Depending on these subjects, the main purpose of this study is to clarify why it is needed to search for a new, fair and analytical delay analysis and also a hypothesis was mentioned.

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## Requirements analysis for a project-related quality management system in the construction execution

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**ABSTRACT:** Quality problems in the execution of construction work were and are a common problem. At present, various support systems for quality control have been developed. However, these existing systems mostly deal with company-related quality management or focus on quality control. Therefore, no requirements for project-related quality management have been considered. This article aims to analyse and to define requirements to design and evaluate a project-related quality management system for the construction execution. The requirements for a project quality management system are derived by a literature review in combination with a system analyses using the system theory and based construction process analyses.

# APPLICATIONS of ARTIFICIAL INTELLIGENCE

## Metadata based multi-class text classification in engineering project platform

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**ABSTRACT:** Enterprises usually establish digital platforms to store and share projects as well as business data. Those files in digital platforms usually have metadata that gives information about the life of a document. Metadata is useful to retrieve useful information about the document. They can be generated fully automatically or given manually by users. Sometimes those manually given metadata can be left out, insufficient, or even wrong. Those metadata stay unaware until the files are being searched for a purpose later on. If the number of files with insufficient metadata is enormous, the filtering of files from platform according to specific metadata becomes difficult. Manually correction can be tedious and enormously time intensive. This paper introduces a method for correcting faulty metadata based on other correct metadata with text classification, natural language processing technique, and linguistic synonymy information in the engineering project platform. The proposed method is evaluated on a real-world dataset. Even though the available information from metadata is limited, the method still gives a promising result and has the advantage of its high computing speed.

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## Using topic modeling to restructure the archive system of the German Waterways and Shipping Administration

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**ABSTRACT:** The German Waterways and Shipping Administration (WSV) is responsible for a large number of technical documents in its archive system. These include the design process in accordance with its administrative regulations (VV-WSV), which covers the entire planning cycle from basic evaluation to implementation planning. In the process of planning, construction and operation of objects of the hydraulic engineering infrastructure, a large and varied number of documents is being accumulated at the responsible authorities. Hierarchical filing systems provided with metadata are often not sufficient to search the documents in a targeted manner. The object of research is therefore machine learning methods that generate new classification systems on the basis of the given document stock and can integrate the existing documents into them. The filing is object-related and the clerk specifies various descriptive attributes. Of interest are now procedures that automatically generate topic models on the basis of the specified texts in the metadata documents in order to assign the documents to them. For this study, the words in the metadata attributes were combined into so-called bag of words and latent Dirichlet allocation (LDA) was applied to automatically find word groups that belong together. With the topic models generated in this way, documents can be searched according to topic composition or, in the case of a keyword search, documents can be displayed which do not contain the keyword but which match the topic. Due to the high number of topics that overlapped within the planning data and the few words per document, the algorithm found it difficult to generate unambiguous topics that could be easily interpreted by humans. In order

to generate such topics, so-called Seeded LDA was used. Here the generation of topics can be influenced by setting seed words per topic. With Seeded LDA it is possible to fix certain topics while the algorithm decides others freely and finds new topics.

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## Applying weak supervision to classify scarce labeled technical documents

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**ABSTRACT:** The digitalization in the construction industry, the number of project relevant documents. It becomes a challenge to organize documents in a searchable manner by classification. The German Waterways and Shipping Administration (WSV) is one of the organizations facing this problem. Manually classifying is due to the considerable expense nearly impossible. In parallel, text classification with machine learning increasingly draws attention. Classification belongs to supervised machine learning, where large labeled data samples are needed. In the filing system used in WSV, only a small amount of data with ground-truth labels are available. It is tedious and expensive to annotate manually. To solve the shortage of training data, we propose applying weakly supervised learning, where noisy and inexact labels can be used in the training process. In this study, we inject the domain knowledge in the training process with weak supervision framework Snorkel to construct a labeling model that programmatically annotates data. We then trained classifiers on the original dataset together with the dataset annotated by the labeling model. The results show that even though the programmatically annotated dataset is noisy, it can still train a generalized classifier and improve the classifiers' performance.

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## Defeasible reasoning for automated building code compliance checking

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**ABSTRACT:** We present a new approach and a prototype software engine for defeasible reasoning to support automated building code compliance checking. The challenge with formalising defeasible rules in a purely deductive reasoning system is the resulting exponential blow up of the rule set due to the need to explicitly state numerous combinations of exception cases. This leads to a rule set that is brittle, complicated, difficult to understand, and obscures the central point of a given normative provision. Moreover, assessing compliance, to any

degree, in the absence of complete information about a building, down to the smallest detail, is very limited in a purely deductive setting in which nothing can be assumed. We empirically evaluate our prototype reasoning engine on an IFC model of a building in Christchurch, New Zealand, for compliance with accessibility criteria from the New Zealand Building Code.

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## [An AI-based approach for automated work progress estimation from construction activities using abductive reasoning](#)

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**ABSTRACT:** Current standard approaches for monitoring site progress for lean construction favor weekly or bi-weekly meetings. All trade and construction site management representatives meet to synchronize the forthcoming schedule. Up-to-date information is often not available, causing poor coordination and resulting in delays, rework and waste of monetary resources. Furthermore, infrequent updates on work performance impact scheduling of critical activities. This paper investigates the possibility to automate some tasks in progress monitoring by applying an AI-system with abductive reasoning on real-time localization sensing data (RTLS) and domain expert knowledge. The work proposes a framework, consisting of three modules (data preparation, processing, and update) that utilize abductive reasoning. An experiment was conducted on previously collected data Teizer et al. (2013) to compare progress inferred from the framework with actual progress recorded. The preliminary results indicate the framework is able to reason about progress with high degree of similarity to the paper of Teizer et al. (2013), however, solely based on RTLS data and without any manual input. The future of the framework is promising since it supports the analysis of time series, allowing it to be applied nearly simultaneously to data collection, and thereby significantly increasing the update rate for information.

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## [Assumption of undetected construction damages by utilizing description logic and fuzzy set theory in a semantic web environment](#)

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**ABSTRACT:** Within the scope of non-destructive inspections, it frequently happens that damages within the construction structure or at inaccessible areas are not detected. Thus, human experts must assume these damages by evaluating relevant information about the construction and its surroundings, which could become a time-consuming and error-prone task. For this reason, a new approach is presented in this paper, in which a knowledge system has been developed utilizing Semantic Web Technologies to automatically infer new information about potential undetected damage areas based on past generalized experiences. Thereby, ontological models for defining information about the affected construction and the already inspected damages are used as data input and reasoned by applying predefined rules

formalized in Description Logic. Furthermore, the possibility for occurrence of each assumed damage is determined by utilizing fuzzy set theory.

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## An overview of data mining application for structural damage detection in the last decade (2009–2019)

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**ABSTRACT:** Data mining becomes well-known by the public nowadays. Thanks to the novel updating of programming languages and computer hardware, data mining in the last decade arises rapidly, and shows a board spectrum of varied algorithms and diverse application domains. Focusing on structural damage detection, in which the related concepts e.g. system identification, structural health monitoring, etc. are also involved, this paper investigates frequently utilized data mining algorithms, summarizes the corresponding application scenarios and indicates the tendency of data mining development according to the academic publications from 2009 to 2019. With respect to application objectives (such as stiffness estimation, damage recognition, and sensor placement), algorithms are grouped into three categories: cluster analysis, classification methods and global optimization. In each category, the algorithm principles are introduced, the corresponding applications are systemically elaborated. Finally, the overview of data mining application is summarized and discussed.

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## Intelligent structural design in BIM platforms: Optimization of RC wall-slab systems

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**ABSTRACT:** This paper evaluates the performance of a genetic algorithm (GA) in generating an optimal RC shear-wall slab structure for a given architectural model in IFC (Industry Foundation Classes) format. The concept of the optimization procedure is first outlined. Then a sensitivity analysis is carried out to find out the adequate weights of the multi-objective function to control the torsional eccentricity ratio, the total length of the shear walls, the covered and overlapping area related to the gravity load bearing. The results demonstrate that a proper use of weights is essential in generating optimized layouts which comply with the architectural configurations and satisfy the predefined seismic design criteria for a wide range of building architectural schemes. A repeatability test confirmed the robustness of the procedure. The outcome of this study can help tuning the optimization procedure by providing weight ranges that can be used for different structural and architectural design conditions.

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## METIS-GAN: An approach to generate spatial configurations using deep learning and semantic building models

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**ABSTRACT:** In order to recommend architects design options, a system was developed which uses artificial intelligence (AI) methods of case-based reasoning (CBR) and deep learning. Since the system uses deep learning, it requires a sufficient amount of data for training, but currently, not enough amount of semantic building data is available publically. In this paper, a Generative Adversarial Network (GAN) is considered to generate the semantic building data to train a Deep Neural Network (DNN) to recommend design options.

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## Practical experiences from initiating development of machine learning in a consulting engineering company

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**ABSTRACT:** There are high expectations for the impact of Machine Learning (ML) in general. However, applicable solutions in the AEC/FM industry are hard to observe. This paper shares experiences from a pilot project in a consulting engineering company utilising existing geotechnical data to develop a ML-based solution based on supervised learning. Even if the case is domain specific, the experiences from the process should be of general interest. This study documents that relatively much can be done by limited investments. Access to enough relevant data for development (training) of algorithms was identified as barrier, in addition to a time demanding process for preparing relevant data. Applicable competency includes both to understanding of the problem, exploring relevant data and developing the digital ML-software solution. This case shows that learning by doing can be away to develop the relevant competency. ML-projects should therefore be regarded as a learning process to be started promptly.

# DIGITAL TWINS and CYBER-PHYSICAL SYSTEMS

## A cyber physical system for dynamic production adaptation

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**ABSTRACT:** This paper introduces the Geo Production 4.0 platform, a cyber physical system (CPS) for dynamic production adaptation based on predictions of system development with focus on all types of basic structures such as deep construction pits, tunnels, underground tubes or culverts. The results show that static problems resulting from inaccurate predictions during the construction process can be identified early with the help of CPS and solved inexpensively by timely adaptation of the production process.

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## A framework for development and integration of digital twins in construction

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**ABSTRACT:** Generation and sharing of data have always been critical within the Architecture, Engineering, Construction and Operation (AECO) sector due to its fragmentation and it is well recognized that this led to an inefficient and poor integration of processes along the building lifecycle. Despite the introduction of Building Information Modelling (BIM) that enhances interoperability many issues related to the management of information evolution still persist. Management of vast amount of data is complex especially in change management process during construction phase when a real-time processing, integration and immediate feedback are usually necessary. In order to exploit the potential of digital technologies for process efficiency improvement linking directly to BIM models and defining BIM processes is necessary. Product Life-cycle Management (PLM) and Model-Based Systems Engineering (MBSE), commonly applied to other engineering fields, embody the key approach to complex construction management and model-based information use. The challenge is not only to support the various phases of the building's life cycle, but also to capture its multidisciplinary nature which has led to the creation of various frameworks. To this aim, "digital twin" with its dynamic digital representation of the physical system continuously updated with latter's performance, maintenance and health status data can represent a valuable tool. However, current MBSE digital twins face the following challenges: specific domains applications, unrelated modelling theories, different semantic models and uncommon storage representations. All these issues led to seamless integration across disciplines during the whole lifecycle. MBSE toolchain is an emerging technique in the area of systems engineering which is expected to become a next generation approach for supporting complex Cyber-Physical System (CPS) development as the integration system of systems. This paper proposes a framework for development of digital twin integration based on MBSE toolchain technique, providing a semantic integration among layers such as social (integration of stakeholders' views), process integration of management models for process control and monitoring), technical (integration of domain specific model for predictive co-simulation), information (integration of data, model and tool operations). The framework has two main purposes: to support toolchain development with a Model Based System Engineering approach; to promote interoperability of the whole developed toolchain through a service-oriented approach where services are

provided to the other components by application components, through a communication protocol over a network.

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## A Digital Twin factory for construction

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**ABSTRACT:** As our society is becoming increasingly interconnected, the construction industry is faced with unparalleled needs for digital infrastructure as it is beginning to adopt sophisticated cyber-physical integrations, known as Digital Twins. Previous work on BIM and cyber-physical systems within the construction sector as well as from nearby engineering fields have already contributed significantly around the subject of digital twins in terms of their definition and potential uses across several construction application domains. We propose the concept of a Digital Twin Factory within the Architecture, Engineering and Construction sector, which is aimed to support the rapid deployment of construction site digital twins in a more practical sense. Within this article, we outline the initial requirements followed by a potential blueprint on what a Digital Twin Factory should resemble and what its main roles are in creating, hosting and updating the data about the construction site on multiple levels.

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## Lifecycle oriented digital twin approach for prefabricated concrete modules

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**ABSTRACT:** Building Information Modeling (BIM) is increasingly used throughout the construction industry as a crucial tool for project management. In order to use BIM throughout the entire life cycle of a building, aspects of production, maintenance and renovation of the structure must not be neglected, especially if the share of industrial prefabrication with corresponding modularization increases. The challenge is also to digitally support new prefabrication and production concepts during the design and recycling process. In this paper, the authors present an approach to transfer digital twin concepts from the field of mechanical engineering to civil engineering and thus extend current BIM approaches by cyber physical components. As a use case, the production of pre-cast concrete modules made of free-form high performance concrete in the construction industry is presented and in particular a concept

for the transfer and systematic collection of requirements, relevant information models and interactions that form an administrative shell for digital twins in BIM environments.

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## A Digital Twin as a framework for a machine learning based predictive maintenance system

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**ABSTRACT:** Due to the advancing digitization in the building industry, improving sensor qualities and growing opportunities of wireless technologies, the potential and possible applications of a digital twin in connection with IoT-Devices (Internet of Things) enlarges. Therefore, the field of implementing digital twins in the AEC (Architecture, Engineering & Construction) sector will be examined in this paper and in relation to the research project ZEKISS. In this project an AI (artificial intelligence) will be developed which is meant to give predictions of the structural health of railroad bridges based on structural FE-models and real-time sensor data. The foundation for the connection of the gathered data and the structural elements of the bridges is the developed digital twin. In the scope of ZEKISS, the definition of a digital twin goes beyond the 3D representation of real objects and the linking of the sensors to the digital elements as known from the BIM method. Furthermore, the digital twin is seen as the whole framework with the AI as the core-element on which any kind of necessary simulation can be performed.

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## Semantic contextualization of BAS data points for scalable HVAC monitoring

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**ABSTRACT:** Buildings account for approximately 40% of the total primary energy use in the U.S. and EU, while building systems waste a lot of energy due to poor operation and faults. Automated fault detection and diagnostics (AFDD) can be used to reduce the energy waste and ensure occupant comfort, and to support monitoring-based commissioning (MBCx). Applying the methods to existing buildings is cumbersome due to poor data labeling. Scaling the methods to account for different types of buildings requires a flexible way of mapping the data points to relevant monitoring processes. This paper proposes a novel method of using a semantic model to contextualize the data points for downstream analysis applications. The method is evaluated with application examples, and further potential applications are discussed.

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## Integrating sensor- and building data flows: A case study of the IEQ of an office building in The Netherlands

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**ABSTRACT:** The need for integrating building data with other data sources is growing, most notably sensor data. This potential synergy between building and sensor data flows has been researched, but current research is aimed almost exclusively at the automation of transmitting sensor data to building models, although often not focusing on operational and analysis possibilities with the integrated data. This research aims to effectively integrate sensor and building data flows for analysis purposes. Using the developed integration, multiple data sources can be effectively utilized for analysis. Its functionality is proven in this paper on hourly Indoor Environmental Quality (IEQ) analyses of a University Medical Centre (UMC) office building. These results prove that, using building information, measured sensor values can be placed into context, and actionable insights can be derived instead of manually interpreting the sensor results.

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## Abstract life-cycle modeling of cyber-physical systems in civil engineering

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**ABSTRACT:** With recent advancements in embedded sensing technologies for the Internet of Things, cyber-physical systems, instrumented with structural health monitoring and control applications, are increasingly implemented in civil engineering. Several approaches towards metamodeling cyber-physical systems in civil engineering have been proposed in recent years, based on Unified Modeling Language (UML), category theory, and abstract algebra. However, life-cycle metamodeling of cyber-physical systems (CPS) in civil engineering has not yet been addressed in its full generality. The evolution of a CPS during its life cycle typically requires the evolution of the corresponding metamodel, because different components of a system may be added or removed. Therefore, life-cycle metamodeling approaches must provide possibilities to describe temporal behavior of CPS components, which is not supported by current metamodeling approaches utilized in civil engineering practice. Thus, in this study, an abstract modeling concept for integrating temporal evolutions of cyber-physical systems in civil engineering into existing metamodeling approaches is proposed. The integration starts with a detailed description of a typical CPS life cycle in civil engineering, underlying unique features for each life-cycle phase. The features characterizing phases of a CPS life cycle are abstracted and formalized by abstract algebraic constructions, supporting diagram-based modeling

approaches, such as UML. Finally, an illustrative example of abstract CPS life-cycle modeling for additive manufacturing of concrete is presented.

# PHOTOGRAMMETRY, LASER SCANNING and POINT CLOUDS

## Combining point-cloud-to-model-comparison with image recognition to automate progress monitoring in road construction

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**ABSTRACT:** This paper proposes a method to recognize the current progress of a road construction site by combining geometric comparison of 3D CAD geometry to as-built point cloud data with image-based surface recognition. Recognizing the current status of road construction sites by purely geometric means is error-prone, since the individual road layers are relatively thin compared to possible deviations of the built road from the design geometry and possible inaccuracies in the z-dimension of the as-built point cloud. Recognizing the current state by purely visual means is prone to error if two or more layers look alike or if the appearance of a layer is distorted by e.g. dust. Therefore, we propose to merge the geometric and the visual evaluation into one hybrid probabilistic algorithm. The goal is not only to improve the accuracy of the progress recognition, but also to gain additional information about the confidence of the systems decision.

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## Research on BIM and virtual pre-assembly technology in construction management

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**ABSTRACT:** In the field of architecture, the virtual pre-assembly of prefabricated components (steel structure, some of concrete structure) need to obtain data through 3D laser scanning or other instruments, and then realize by computer virtual imitation. In recent years, the combination of BIM and virtual pre-assembly is more and more used in some large and complex steel structures, especially in the application of technology, and the effect is good. However, for the combination of BIM and virtual pre-assembly, there is little research on management. In this paper, the combination of BIM and virtual pre-assembly in the management of the application of a more in-depth study. Compared with the traditional

construction management, the combination of BIM and virtual pre-assembly optimizes the key construction steps such as construction preparation, quality inspection, schedule management, resource coordination, etc., which can serve the whole life cycle of the project. We have applied the combination of BIM and virtual pre-assembly to the construction management of a large complex steel structure. The results show that the integration of BIM and virtual pre-assembly technology has many advantages over the traditional construction management. It can find some problems that traditional management can't find in advance, and allocate resources reasonably.

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## The use of the BIM-model and scanning in quality assurance of bridge constructions

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**ABSTRACT:** For bridges with complex structures and difficult construction, quality is a real issue. The use of the BIM-model is important to seek good quality in the design of the bridge. Furthermore, the model is important for construction and supervision, but it is undeniable that quality assurance after completion could be a problem. The use of a scanner could ease this problem. The bridge completion state mode is collected by 3D laser scanning technology. The theoretical model is compared with the actual state, so that the concrete bridge member is subjected to three-dimensional digital detection such as dimensional deviation and flatness of the surface of the member.

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## Application of phase three dimensional laser scanner in high altitude large volume irregular structure

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**ABSTRACT:** The precise measurement and positioning of the outline of high-altitude massive special-shaped structure has a guiding role in the installation of its external curtain wall and other ancillary facilities. Traditionally, total station measurement and other technical methods are mostly used, which have the disadvantages of large workload, long time-consuming and low accuracy. This paper takes the high-altitude corridor enclosure structure of Chongqing Raffles Square as the research object, combines the characteristics of Leica Nova MS60 high-precision three-dimensional laser scanning total station which can accurately locate and Faro x330 three-dimensional laser scanner which can scan quickly, and puts forward an excellent combination of two instruments. Based on the point scanning method and the mathematical optimization theory, a high-precision registration formula for point clouds with special-shaped structures is derived. On the premise of meeting the registration accuracy of point clouds, the rapid scanning and global positioning of a large number of special-shaped components are realized, and precise data are provided for the rapid extraction of contours. It has great application prospects and important applications in reverse modeling and deviation analysis.

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## Automatic detection method for verticality of bridge pier based on BIM and point cloud

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**ABSTRACT:** Bridge pier is a building that supports bridge span structure and transmits dead load and live load to foundation. As the main supporting structure of the whole bridge, the perpendicularity of the pier is particularly important. Among them, for the pier with high height, the influence of perpendicularity deviation on the quality of pier is more obvious. In this paper, an automatic detection method of pier perpendicularity is proposed. The 3D laser point cloud is used to obtain the spatial attitude of the pier, and the point cloud of the reliable feature surface of the pier is extracted by combining the automatic recognition algorithm. According to the principle of statistical correlation, the characteristic surface data of piers are processed to get the actual center line and section of piers. At last, we update the BIM model of the designed pier with the center line and section and analyze the 3D deviation between the updated BIM model of the pier and the point cloud. We apply this method to the verticality detection of several bridges. The results show that the method is reliable and robust.

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## Application of railway topology for the automated generation of geometric digital twins of railway masts

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**ABSTRACT:** The digitisation of existing railway geometry from point clouds datasets, referred to as “twinning”, is a labourious task, which currently outweighs the perceived benefits of the resulting model. State-of-the-art methods have provided promising results, yet they cannot offer large-scale element detection required over kilometres without forfeiting precision and labour cost. The authors exploit the potential benefits of railway topology to automate the twinning process. The preliminary step involves automatically detecting masts as their positions are critical for the subsequent element detection. The method first removes vegetation and noise. Then it detects masts relative to the track centreline using the RANSAC algorithm and delivers final models in IFC format. The authors validated the method on an 18 km railway point cloud dataset and the results yielded an overall detection accuracy of 90.1% F1 score and reduced the manual twinning time by 98.6%. The proposed method lays the foundations to efficiently generate geometry-only digital twins of railway elements with no prior information.

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## Project controlling of road construction sites as a comparison of as-built and as-planned models using convex hull algorithm

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**ABSTRACT:** Continuous project control is crucial for the benefit of a smooth progress in construction projects. It implies the comparison of the target model with the actual situation of the building site. The aim of this work is to gain a comprehensive insight into project controlling via UAS photogrammetry and to give an example of implementation by a real case project. The method uses an approach that uses as-built point clouds and the as-planned model to estimate the degree of completion of road constructions work to using convex hull algorithm. The algorithm is a so-called cluster algorithm and is used in the data mining area. By enlarging this BIM model with the scandate and to 5D the costs are also monitored during the construction phase. Thus, an automated and practical project controlling will be developed. This implementation proves that a photogrammetric UAS controlling for degree of completion in road construction projects is feasible.

# CITY and BUILDING INFORMATION MODELING

## A trend review on BIM applications for smart cities

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**ABSTRACT:** To respond to the challenges like population growth, climate change, economic instability, cities are taking a data-driven, modern technology-oriented approach to provide better service, improved quality of life and a sustainable future. With the advancement of technologies, such as Building Information Modeling (BIM), applications of information integrated 3D models have started gaining popularity among the architecture, engineering, and construction (AEC) researchers. Considering the benefits of BIM and the requirements of smart cities, the amalgamation of BIM and smart city research was obvious. As the researches in both fields have become mature, a review of the BIM applications in the context of smart cities is much needed at this point. Ninety-two (92) papers from two major online databases were retrieved and analyzed through a systematic literature review approach. Results show that present researches are mostly focused on technology advancement. Six major research directions are observed. Sustainability, facility management, and construction management related researches have been discussed most frequently.

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## Matching geometry standards for geospatial and product data

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**ABSTRACT:** Integration of data from the construction and geospatial domain relies on successful integration of the respective geometric components. In this paper we report on some issues encountered during conversion of building models in IFC format to city models in CityGML format. Our results reflect on the ISO geometry standards in the two domains and we present a framework to successively extend the analysis from single observations to the whole standards.

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## City and building information modelling using IFC standard

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**ABSTRACT:** The modern construction industry is moving towards the wide adoption of Building Information Modelling (BIM) technologies and their further evolution for City Information Modelling (CIM) problems. As these concepts are developed to solve multidisciplinary problems, open standards IFC and CityGML are becoming increasingly important. Despite numerous attempts to integrate data driven by these standards, software scalability and interoperability issues remain critical due to the complexity and heterogeneity of BIM and CIM models. In this paper an alternative approach to CIM is proposed and explored. The approach implies a hierarchical decomposition of a large CIM model into smaller models represented as linked IFC project datasets. The approach allows Levels of Detail (LOD) generation and visualization methods, provides high scalability for applications, and eliminates the need to harmonize the standards. This approach has been successfully validated by the development of a software application designed to visualize large-scale urban environments at different levels of detail.

ENVIRONMENTAL, SOCIAL and ECONOMIC  
DIMENSIONS of SUSTAINABILITY

## Evaluating the concept and value of smart buildings for the development of a smarter procurement strategy

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**ABSTRACT:** The digital revolution has created new smart technologies like, smart phones, smart services, contactless payments, that have changed the way people live and interact with each other. These technologies have created a frictionless lifestyle for the modern people. These features and technologies are available because of 'big data' approaches and Internet of Things (IoT). Today the building industry is moving towards building designs with more complex and integrated systems. Drivers for this change are efficiency, convenience, cost savings, energy savings, enhanced communication etc. This research is focusing on a strategy for procurement of smart buildings with the aim of highlighting potentials and challenges with the collaboration of the stakeholders in the building industry especially with the focus of bringing the facility management in focus and defining critical requirements in the early design phase.

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## From linear to circular: Circular Economy in the Danish construction industry

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**ABSTRACT:** The construction industry relies predominantly on the take-make-dispose principle. That contributes significantly to resource depletion and creates a considerable negative environmental impact. Therefore, a paradigm shift is necessary, which helps achieve sustainable processes and minimises the negative contributions. Circular Economy is based on the principle that the value of products, materials and resources is maintained as long as possible by reusing and thereby minimising waste. However, Circular Economy is still to be adopted at a larger scale. This paper presents a methodology for assessment of the circularity level of AEC organisations and enables the discovery of specific actions which can lead the way to a circular industry. The method provides a measure of the current state of the company processes in accordance with five Circular Economy pillars. The results show that implementing Circular Economy is associated with motivating the companies to take action, strengthening collaboration, and implementing circular processes.

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## A BIM-based tool for the environmental and economic assessment of materials in a building within early design stages

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**ABSTRACT:** Sustainable decision-making is gaining momentum in building impacts assessment for improving the design, specifically from environmental and economic perspectives. Fast and accurate assessments can be made for the determination of building materials in earlier designs by integrating the environmental and economic assessment principles with building information modelling (BIM). Currently, there is a lack of assessment tools that can be applied for the assessment of environmental and economic impacts simultaneously within the early design stages of a building. This paper identifies the potentials of integrating BIM with life cycle assessment (LCA) and life cycle costing (LCC) by developing a tool that allows designers to optimize their designs based on impacts assessment in early design stages. The findings suggest that BIM has an interesting potential for the integration of LCA and LCC, and aids designers in making well-considered environmental and economic decisions related to the building materials in early design stages.

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### Housing energy-efficient renovation adoption and diffusion: A conceptual model for household decision-making process

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**ABSTRACT:** Residential buildings have great potential for energy saving and reducing greenhouse gas emissions by energy-efficient renovation (EER). EER technologies are proven to be economically viable. However, the housing EER diffusion process falls behind the expectations. A literature review is conducted to find what the models used to describe the EER adoption decision-making process are and what the influences are. Behaviour theory and social network theory are introduced as complementary information for the review. Findings of the review suggest that there are differences among the research findings and there are limitations when applying behaviour theory in EER field. A conceptual model is presented based on the review. The model includes influences such as household background, experiences, ability, subjective norm, opportunities and information and physical resources. It contains the usual influences from behaviour theories and emphasizes the influences proven have significant impact.

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### Digital technologies as a catalyst to elevating IPD+BIM synergy in sustainable renovation of heritage buildings

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**ABSTRACT:** The implementations of Integrated Project Delivery (IPD) and Building Information Modeling (BIM) for sustainable renovation of heritage buildings are considered to be very efficient to achieve a balance between sustainable design and the historical preservation, as well as to enhance productivity/efficiency in processes, catalyzed by digital technologies. The aim of this paper is to explore, identify, and discuss the relevant digital technologies as a catalyst to elevating IPD+BIM synergy in sustainable renovation of heritage buildings. The research adopts a mixed methodology through application of an analytical framework (with a set of defined variables consisting of 46 criteria, classified into 15 categories, and grouped into five thematic strands - people, process, policy, technology, and product) besides triangulation approaches for data collection and validity of the research work. We investigate on how the digital technologies open up new possibilities and where they add or are expected to add value.

## BIM EDUCATION and TRAINING

## Analysis of digital education in construction management degree programs in Germany and development of a training model for BIM teaching

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**ABSTRACT:** The Building Information Modeling (BIM) methodology plays a key role in the digital transformation of the architecture, engineering, and construction (AEC) industry. The development of digital technologies, especially software programs for 3D design, engineering and construction, model-based quantity determination, calculation and scheduling or application of artificial intelligence in AEC, supports BIM use cases that were previously not feasible. Nevertheless, a human being must be able to master the digital technologies to implement the BIM methodology and achieve BIM goals. Well-trained specialists with BIM qualifications are in demand on the AEC job market today. The aim of this article is to analyze construction management degree programs in Germany regarding their anchoring of BIM in the curriculum. Based on the analysis and the derived requirements, a concept for a training model for the targeted BIM teaching of construction managers at higher education is proposed.

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## Experiences from large scale VDC-education in Norway

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**ABSTRACT:** This study investigates how a new approach for large scale education can solve the need for increased performance in design and construction projects. A large-scale course in Virtual Design and Construction (VDC) with 200+ participants in Norway is used as a case for assessing this type of learning environment. The study is done by collecting assessment of student's feedback and student reports from real projects. The results are analyzed through the lens of the "Community of Practice" (CoP) theory. This theory explains why the learning outcomes in knowledge, skills, and attitude can be relatively higher than with traditional classroom courses with 20 participants. The impact of organizing the learning environment as a CoP can contribute to fill the competency gap in the construction industry in a very efficient way. A good course is not only about content, but to create confidence to change current practice and performance.

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## The efficacy of virtual-reality based safety training in construction: Perceptions versus observation

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**ABSTRACT:** The construction industry is widely regarded as a high-risk environment that is also known for its high fatalities and injury rates. The lack of appropriate health and safety training is a leading cause of accidents on construction sites. In recent years, several industries have experimented and gradually employed Virtual Reality (VR) technology to enhance safety training. Unlike traditional health and safety training that relies on a one-way instructional method of delivering information, VR provides experienced-based learning by placing the user inside a drill. This paper reports on a preliminary study that sought to assess the size of the efficacy of VR-based training within the construction industry context. By utilizing a mixed-method case-control research methodology, the study compared achievements made through the traditional methods of health and safety training such as the use of PowerPoint presentations against VR-based training. The achievements were evaluated based on the immediate perception of the trainees compared to the actual observations afterwards. The study focused on two particular aspects of the training outcomes: (1) impact on the knowledge retention by the trainees to identifying risks on construction sites, and (2) influence on their future risk-taking behavior. Eight residential construction sites in Auckland, New Zealand were selected as the indicative clusters of construction activities in the region. Correspondingly, a simple random method was applied to select one of the sites and sample ten trainees from the nominated site. Accordingly, a control group of five professionals received approximately 25 minutes of traditional health and safety training. An intervention group of another five professionals received the same length of health and safety training while using VR technology. After each training session, the groups were interviewed through the use of face to face semi-structured strategy twice. In both rounds of the interviews, the respondents were quantitatively assessed by rating their responses on a 5-point Likert scale. The first round was conducted immediately after the training session. It graded the perception of the respondents about their level of engagement and satisfaction, besides the impact of the session on their future safety behavior. In order to examine the genuine achievements of the training sessions, the second round of interviews was instituted the day after the training session. It assessed the participants' recall of the training contents and their risk-taking behavior in a hypothetical scenario. Despite the strong belief from trainees about the effectiveness of the VR technology in improving their health and safety learnings, no significant difference was observed in their risk-taking behavior and risk identification ability. Furthermore, some cases of nausea and dizziness were observed when using the VR headsets. The results can be generalized only if the future studies with bigger sample size show a similar outcome.

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## Applying activity theory to get increased understanding of collaboration within the VDC framework

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**ABSTRACT:** Improving process performance in projects is challenging; systemic change requires methods that combine prioritised elements to optimise continuous improvement. Projects that have implemented the Virtual Design and Construction (VDC) framework document improvements in process and product performance. These projects have made multiple changes in their way of working and collaborating. However, there is a difference in observing “what” is done in practice, to explain “why” changes brought by e.g. VDC have these effects. This paper uses Activity Theory to understand and demystify VDC. Theory-based reflections and experiences from 200 students in a Norwegian VDC-course are used as reference for critical reflections. The results of these reflections show that there are connections between multiple activities that contribute to systemic improvement. The impact of this type of understanding makes implementation of the VDC framework clearer. Combining theory and practice gives potential to get better results with less effort.

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## A conceptual method to compare projects by combining assessment of controllable and non-controllable factors

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**ABSTRACT:** Systemic methods to assess and compare project processes considering their context are missing in the Architectural Engineering Construction (AEC) sector. Project assessments are highly dependent on the factors that define their context, making comparisons challenging. Inspired by interventions from macroeconomics that use empirical factors to simplify contextual complexity, project comparison can be integrated into assessments. This paper discusses a conceptual method to combine statistical methods of project context and numerical measurements of project process in Virtual Design Construction (VDC) projects. The method proposed suggests ways to break the bottleneck of assessing projects independently using streamlined big data sources from real projects. The study raises awareness to integrating numerical (process) and statistical (context) data. By this combination, a concept for intelligent performance metrics is discussed.

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## The practice of VDC framework as a performance measurement system for projects

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**ABSTRACT:** The use of Virtual Design and Construction (VDC) methods, tools and practices coupled with powerful business analytics can provide a solution to the construction industry's long-standing performance measurement problems. The study opts for a pragmatic approach to investigate the perception of the VDC practitioners to use VDC framework as a performance measurement system for projects through an online survey. It further explores the hidden relationships in the perceptions of the VDC practitioners through the application of data analytic tools. Results indicate that the VDC framework has the potential to be practiced as a performance measurement system for the construction projects. The study is unique in the approach and is targeted at the VDC practitioners and academics aiming to digitalize the performance measurement in construction industry.

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## Exploring the degree of automated process metrics in construction management

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**ABSTRACT:** Process metrics are commonly used in many industries to monitor and track different business processes, but in the construction industry there is currently no unified method. However, there is a trend towards establishing both qualitative and quantitative metrics, mostly on product performance. Identifying process metrics are crucial for all project teams that want to track their performance, provide documentation on progress and to detect areas of improvement. The essence is therefore to collect data and to provide information about the progress toward reaching client and project objectives. This paper aims to explore the possibilities to automate different process metrics that is already measured by students, in their respective projects and organizations, in a large-scale Virtual Design and Construction (VDC) course. A methodology to assess the *degree of Automated Process Metrics* (APM) is developed.

ORGANIZATIONAL, PERCEPTUAL and  
TECHNOLOGICAL ISSUES of BIM ADOPTION

## “We need better software” – the users’ perception of BIM

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**ABSTRACT:** This paper explores how the users’ perception of BIM impacts the implementation of BIM. Semi-structured in-depth interviews were conducted with BIM users in the Real Estate department in a Norwegian municipality. The goal is to uncover in-depth understanding of BIM and related practices of BIM stakeholders. Our findings show that the BIM-users’ perception of BIM has a significant impact on their activities. BIM is seen as an add-on to traditional roles and responsibilities, where you must use BIM-software to be a BIM user. This study recommends, based on deep studies in innovation research, a shift to invest in people rather than software to increase the speed of BIM adoption.

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## Development needs on the way to information-efficient BIM-based supply chain management of prefabricated engineer-to-order structures

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**ABSTRACT:** Effective information management impacts the overall success of the construction project and is particularly vital in projects utilizing engineer-to-order (ETO) prefabrication, which is especially vulnerable to missing information. Therefore, this study focuses on ETO prefabricated structural steel and concrete components and how the related supply chain management could be improved by more comprehensive and effective application of the Building Information Modelling (BIM) environment for timely exchange of information between the parties involved throughout the delivery process. Current application of BIM falls short of its potential. Therefore, the study also identifies 25 key areas of development under five management categories drawing, primarily, on extensive dialogue with numerous experts from the industry. As these key development areas are strongly interrelated, their mutual interrelations and reasonable order of implementation are also discussed.

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## Analysis of the influencing factors for the practical application of BIM in combination with AI in Germany

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**ABSTRACT:** By using Building Information Modeling (BIM) methodology in the architecture, engineering and construction (AEC) sector, construction participants create digital building models and produce large amounts of information during the entire life cycle of a building. This generated digital data may also be used for further evaluation, analysis and simulation of machine intelligence. The integration of AI methods into the construction process is feasible in various application areas, such as building design, industrial prefabrication, planning on the construction site and project management. The aim of this study was to identify the factors that influence the practical application of BIM in combination with AI in the German construction industry. In the course of this research, the most important aspects of the country-specific AI initiation relating to BIM data were gathered and evaluated, and, based on this analysis, the potential application-oriented goals of BIM and AI methods can be carried for AEC.

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## [A systematic review of project management information systems for heavy civil construction projects](#)

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**ABSTRACT:** Project success depends heavily on effective collaboration among organizations and individuals and efficient Information and Communication Technology (ICT). Among these tools, Project Management Information Systems (PMIS) are complex, distributed, multi-functional systems for decision-making support when planning, organizing, and controlling projects. However, these tools create new problems such as information overload, increased pressure and communication chaos caused by the complex and volatile nature of projects; they also neglect the particular needs of Heavy Civil Construction (HCC) section, a significant subdomain of the AEC industry where the challenges are much higher than typical projects. Through a systematic review, this paper outlines the landscape of PMIS and it presents the benefits and adoption barriers. The research highlights the lack of holistic applications and proposes new and innovative ad-hoc solutions for efficient management of construction and infrastructure projects to be adopted by the developers, via standardization of PMIS for HCC. The research informs the industry stakeholders, software vendors and policymakers of the industry gaps and the potentials for the development of collaborative solutions for PMIS standardization, similarly to the Building Information Modelling (BIM) technologies.

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## Multi-stakeholder involvement in construction and challenges of BIM implementation

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**ABSTRACT:** Project development is a complex process where many stakeholders work together. Employer and main contractor are the base stakeholders, whereas designer, engineer, sub-contractors, suppliers, supervisors and consultants are other stakeholders. BIM is a tool that should be considered by every stakeholder with the opportunities it offers. The main goal of this paper is to explore the problems associated with the adoption of BIM in multi-stakeholder projects. The paper is a conceptual study, summarizing the author's practical experience with design offices and construction firms working with BIM. In the transition period to BIM, three of the challenges are examined: the compatibility of supplier companies with BIM, the need for two-dimensional drawings, and contractual issues related to BIM. The paper reviews the literature on BIM usage and reviews the challenges in the transition stage to BIM. Finally, a number of suggestions for the future about accelerating BIM use is provided.

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## Impacts of BIM implementation on construction management processes in Turkey

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**ABSTRACT:** In the last decade, construction industry has witnessed emergence of a new tool that claimed itself to drive efficiencies, reduce costs and add long-term value to the development and management of built assets. Building Information Management (BIM) is an architectural, engineering, planning, control and facility management tool that contains all design and quantitative data necessary throughout the life cycle of a project. As a project planning and control tool, BIM occupies the field of traditional construction management systems by replacing planning tools based on two dimensional displaying methods. This research has been conducted to find out effects of BIM implementation on construction management processes by focusing on time, budget and contract management performances, from Turkish construction industry participants' perspective and it contributes to literature by depicting the current state of experiences and observations of Turkish construction industry practitioners on BIM implementation.

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## Building information modeling warnings towards a deadline

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**ABSTRACT:** In large projects, it is common to see BIM warnings accumulate into the thousands. These warnings can be design and reworks related errors. The objectives of this research are to test the hypotheses that most warnings occur up towards a deadline and identify whether the number of warnings increases according to model size. An empirical data collection was used on 33,106 warnings over 32 weeks, then analyzed with descriptive statistics to test the hypothetico – deductive method. The results found that towards a deadline there is an average increase of 9% in warnings from four weeks before the deadline. Although when the model size becomes a part of the equation there is a 4% decrease in warnings per megabyte file size in the same time period. This study finds that more warnings happen close to deadlines, not because of more mistakes, but because of an increase in the work being done.

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## The role of trust in the adoption of BIM systems

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**ABSTRACT:** The adoption of Building Information Modelling Systems (BIM-systems) has not been as straightforward as hoped, and questions must be raised why this is the case. A vital characteristic of the adoption is the “outsourcing” of manually processed information to digital systems and how users perceive data processing. For successful adoption, users need to trust that the digital systems process information according to their expectations. If expectations are not met, users lose their trust like the way when trust is lost between people. This article explores the relationship between trust in BIM systems more widely and specifically what this means for the current adoption. Trust in technology is explored qualitatively through interviews with various BIM-system users. We put forward characteristics to do with trust and digital technology that impact the adoption of BIM-systems.



Over the past quarter century, the biennial ECPPM (European Conference on Product and Process Modeling) conference series, as the oldest BIM conference, has provided researchers and practitioners with a unique platform to present and discuss the latest developments regarding emerging BIM technologies and complementary issues for their adoption in the AEC/FM (Architecture, Engineering, Construction and Facilities Management) industry. The ECPPM 2021 conference is hosted online by the Department of System Integration and Multi-Disciplinary Collaborative Environments of the Ivannikov Institute for System Programming of the Russian Academy of Sciences (15-17 Sep. 2021). High quality contributions are devoted to critically important problems that arise along the way of the digitalization of the AEC/FM domains, including:

- Information and Knowledge Management
- SemanticWeb and Linked Data
- Communication and Collaboration Technologies
- Software Interoperability
- BIM Servers and Common Data Environments
- Digital Twins and Cyber-Physical Systems
- Sensors and Internet of Things
- Big Data
- Artificial and Augmented Intelligence in AEC
- Construction Management
- 5D/nD Modelling and Planning
- Building Performance Simulation
- Contract, Cost and Risk Management
- Safety and Quality
- Sustainable Buildings and Urban Environments
- Smart Buildings and Cities
- BIM Standardization, Implementation and Adoption
- Regulatory and Legal Aspects
- BIM Education and Training
- Industrialized Production, Smart Products and Services

Published by CRC Press/Balkema the book “eWork and eBusiness in Architecture, Engineering and Construction 2021” collects the papers presented at the ECPPM 2021 conference and represents a rich and comprehensive resource for academics, researchers and professionals working in the interdisciplinary areas of BIM.