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6

Theory, ontology, application: Toward a structured representation of occupants in building simulation models

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In the course of building information modeling (BIM) evolution, digital representations of buildings have become increasingly detailed. Similarly, the main concern of building performance simulation (BPS) has been the virtual enactment of buildings' behavior. Naturally, the bulk of efforts to couple BIM with BPS have focused on methods by which geometric and semantic building properties captured in BIM are inherited by BPS. But these properties have been predominantly of a static nature. As such, the constitutive elements of a buildings' geometry and construction and, as captured in BIM, are rarely dynamic. However, whereas classical representations of buildings may mostly involve static elements, buildings themselves function under highly transient boundary conditions, both external (i.e., microclimate) and internal (occupants' presence and behavior). Accordingly, impulses to augment BIM models in view of dynamics have frequently stemmed from developments in BPS. Historically viewed, the early developments in BPS focused on the modeling methods for physical (e.g., thermal, visual, acoustic) phenomena. This was accompanied by high-resolution data sets pertaining to external boundary conditions. In this context, the development of high-resolution models of buildings' occupants has been a comparatively recent concern. Accordingly, the state of art in this area cannot be suggested to have been sufficiently matured. The present contribution thus explores the necessary conditions for the identification and implementation of more robust solutions in this area. To this end, a systematic consideration of three essential layers of discourse are outlined: i) the layer of foundational theories (sources of structured domain knowledge of occupants' requirements with regard to indoor-environmental conditions); ii) the layer of ontology (a shared schema for an interoperable representation and communication of occupants and their behavior); iii) the layer of application (computational implementation of ontologically streamlined processes pertaining to occupants). Given this conceptual background, the contribution introduces a proposal for a theory-driven ontology.

7

Aspects of BIM-to-BEM information transfer: a tale of two workflows

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Achieving seamless transfer of information from BIM (Building Information Modelling) to BEM (Building Energy Modelling) has been the objective of multiple efforts in the building informatics community. To improve the state of art in this area, further efforts are needed. To this end, examination of existing workflows for automated BIM-to-BEM information transfer can help shed light on their effectiveness, thus informing related future activities. In this context, the present paper involves the review of some available semi-automated approaches for information transfer from IFC-compliant BIM tools to a state-of-the-art building energy simulation application (EnergyPlus). The starting point of the case study is synthetic building project, which is modelled in detail in two BIM-authoring tools (ArchiCAD and Revit). These models are subsequently exported to the data exchange format IFC. The IFC files are in turn transformed into EnergyPlus Input Data Files (IDF). The IFC file derived from the ArchiCAD model is transformed via Python scripts using several libraries. The IFC file derived from the Revit model is transformed via the serializer OsmSerializer, which is integrated in the IFC file server BIMserver. The integrity and validity of the resulting geometry and semantic data are analysed. Moreover, the simulation results obtained based on the two IDF instances are compared with each other as well as with a base case model, which is manually created via SketchUp and the OpenStudio plug-in. The findings of the case study point to: i) various challenges and constraints with regard to the generation of BIM models intended for subsequent export to BEM; ii) specific issues concerning the transferability of geometry and semantic data from IFC to IDF via the selected workflows; iii) Inconsistencies in the resulting simulation results. Moreover, the case study provides pointers to enhancement possibilities of specific aspect of the examined workflows.

8

NLP-based Semantic model healing for calculating embodied carbon in early building design stages

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To reach the goals of the Paris agreement of limiting the global warming, the environmental impacts of new buildings need to be quantified and optimized already in the early design stages. Semantic building models, such as Building Information Modeling (BIM), facilitate deriving consistent and automated quantity take-offs of the relevant components for calculating whole building life cycle assessments (LCA). Nevertheless, the early design stages are characterized by high uncertainty due to the lack of information and knowledge, making a holistic and consistent LCA for supporting design decisions and optimizing performance challenging. In more detail, in the "rough" BIM models of early design stages, materials are rather defined by material groups than by specific types, which leads to a range of possibilities for each material group. Furthermore, several materials or component layers might not be defined yet, which gives the opportunity to explore and compare different design options.
Therefore, this paper presents a methodology for automatically mapping the coarse information available at the early design stages, in a process known as semantic model healing. In more detail, the proposed method is based on Natural Language Processing (NLP), using different strategies to increase the performance of mapping materials from a BIM model to a knowledge database with environmental indicators of commonly used components. The knowledge database contains all missing information for LCA and has different levels of detail for a range of several potential design options of components, elements, and materials, including their dependencies. Accordingly, this paper investigates multiple NLP techniques and evaluates the performance of state-of-the-art deep learning models such as GermaNet, SpaCy, or BERT. Finally, the most performant NLP approach is used to provide an automatic workflow for mapping IFC elements to the knowledge database, facilitating a seamless LCA in the early stages of design.

9

A proposed IFC extension for timber construction buildings to enable sound insulation prediction

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To manage climate crisis, carbon emissions should be substantially reduced. This also includes carbon emission from architecture, engineering and construction (AEC) which represents a major factor in mitigating these emissions globally. The sustainability of timber construction encourages more and more architects and planners to chooses this method. However timber construction is a highly specialized way of construction and requires specialized evaluation tools for the seamless application of this construction method. Especially the sound insulation has a high influence on the quality of living and working in the buildings.
Timber buildings with low mass and multi-layered materials include a lot of different details at the joint of elements. Those details are relevant for the flanking transmission of sound and therefore for the overall sound insulation. While the open BIM workflow offers possibilities to use sound insulation prognosis also in early design phases, however, in reality the lack of appropriate software tools slows down this kind of integration. An IFC data model with all relevant input data for acoustic calculation would improve the open BIM workflow significantly.
The aim of this project is to use an IFC data model to find junctions between building elements and to automatically define the necessary junction types for the calculating the insulation according to ISO12354-1(2017). This includes the calculation of airborne sound insulation and impact sound insulation.
In this paper we propose an approach for enriching IFC data models to reach a higher quality for facilitating sound insulation calculations, especially in timber construction. This also includes a definition of IFC entities to correctly describe wooden building elements, especially lightweight elements like stud walls or wood-beam ceilings. Additionally, the transfer of input and calculation data for the sound insulation calculation is investigated in the paper.

10

Automatic Generation of Work Breakdown Structures for Evaluation of Parallelizability of Assembly Sequences

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To enable the efficient construction of industrial plants, seamless logistics on the construction site must be ensured. It can be achieved through precise planning and execution of logistics and assembly. Nowadays, assembly sequences are visually represented in practice using 4D BIM (Building Information Modeling) concept. The assembly schedules on the other hand, are prepared by hand in an imprecise and time-consuming manner. Our previous research has shown that semi-automatic rule-based creation of step-by-step assembly sequences is possible for any IFC (Industry Foundation Classes) models with a high level of detail. Step-by-step assembly sequences are generated by categorizing all building elements in the building model, specifying assembly rules for these categories, and selecting an assembly strategy subsequently. However, a qualitative comparison of these generated assembly sequences is impossible without performing simulation and determining the effort values for each task. To address this issue, this paper presents a methodology for the automatic generation of partial Work Breakdown Structures (WBS) to evaluate the generated assembly sequences. On the basis of the assembly sequence, the assembly rules and the collision database (of slightly augmented bounding boxes of building elements) of a BIM, partial WBS are generated for each individual building element. From the WBS, the length of the longest path to the corresponding start element is retrieved for each building element. This allows building elements to be assigned to the appropriate assembly levels, indicating that all assembly processes that are located in the same level, and thus potentially parallelizable, can be identified.

11

Suitability of three national cost breakdown structures for automated quantity take-off in road projects

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Model-based design enables automated quantity take-off. When it comes to challenges, most studies focus on the technological dimension. Therefore, we analyzed the suitability of three cost breakdown structures for au-tomated quantity take-off and suggested improvements. We selected a qualitative research design based on a document review, interviews, and a software experiment. Both a Norwegian and a German breakdown struc-ture seem to be slightly better suited for automation than a Portuguese one, where construction works, and measurement rules are more process-oriented. All three cost breakdown structures require human knowledge due to their granularity. While all three cost breakdown structures seem to work well for unambiguously quan-tifiable cost items – we called them finished elements – they seem not to work well for earthworks. When it comes to improvements, three areas were uncovered, namely standardization, rules of measurement, and a transition to an object-based approach. As further work, typical finished elements must be identified.

13

Automated Deterministic Model-based Indoor Scan Planning

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Scan planning describes the process of choosing equipment and locations for reality capture with laser scanners. By contrast to the traditional, expert-based method usually conducted in the field, automated approaches aim to solve this task exclusively with pre-existing data in the form of plans or 3D models of the scene. Existing approaches for automation are mostly either limited to 2D or based on simulations of laser scans, which oversimplifies respectively complicates the process to the degree that makes them inapplicable for practitioners. We aim to solve both problems by basing our solution on a 3D representation of the target scene and a deterministic approach. Thus, the workflow remains computationally feasible while the complexity of real-world scenes is sufficiently represented. We present a literature review on related research and technical guidelines for scan planning to define realistic requirements for scan planning, including point density, field of view, and depth of field limitations. To develop valuable strategies, we create a static set of candidate locations on a grid in the scene. We then perform visibility and coverage analysis and evaluate each candidate's fitness for the overall strategy based on its contribution to our pre-defined scan requirements. Finally, selected locations are combined to form an optimized strategy to fulfill these requirements following two versions. We apply two basic methods for candidate selection and investigate their implications in a descriptive experiment.

14

Robust BIM-based 2D-LiDAR Localization for Lifelong Indoor Navigation in Changing and Dynamic Environments

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Several studies rely on particle filter (PF) algorithms for robot localization in Occupancy Grid Maps (OGMs) extracted from building information models (BIM models). However, most ignore the possible discrepancies between the reference model and the real world (Scan-BIM deviations). These deviations affect the accuracy of PF drastically. This paper proposes an open-source method to generate appropriate Pose Graph-based maps from BIM models for robust 2D-LiDAR localization in changing and dynamic environments. First, 2D OGMs are generated from complex BIM models allowing autonomous navigation. Then, a technique converts these maps into Pose Graph-based maps enabling accurate pose tracking. Finally, a robust localization is proposed with a combination of state-of-the-art algorithms. We found that Pose Graph-based algorithms are four times more accurate than PF algorithms by tracking the robot's pose in a real environment. The proposed method contributes to a robust localization with a BIM model in changing and dynamic environments.

15

Towards data mining on construction sites: Heterogeneous data acquisition and fusion

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Data mining methods can invoke substantial optimization potential, as demonstrated in the manufacturing industry. Looking at the construction industry and precisely the as-performed stage, though, this research area is in its infancy worldwide. By now, it is not clear how specific on-site activities can be monitored adequately and how diverse data sources can be combined to make transparent and invulnerable statements about particular on-site activities. The presented study investigates the application of modern data analysis methods to ongoing construction projects to reveal information about specific activities. Raw data from various construction sites has been gained using camera systems, Bluetooth Low Energy (BLE) sensors, and laser scanners to build a powerful foundation of data sources. A data pipeline for integrating different data sources has been developed to handle a large amount and variety of data and its subsequent processing into higher-level information. Using a data mining approach, namely map-reduce, we scaled the significant amount of data down to particular problem-targeted databases. Object detection methods were applied to process images of the construction activities. It was possible to detect on-site construction workers' start and end times, breaks, and location. The introduced results have been verified by using fixed beacons and heterogeneous data types. In conclusion, the presented research provides fundamental methods for examining existing construction processes and collecting data for future analyses.

17

How Practice Is Represented in BIM-Based Model Checking Research – A Literature Review and Reflections

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In both research and industrial reports, one of the major challenges for Building Information Modelling and checking that remains is of a socio-cultural nature, for example, with cultural resistance. While this has remained one of the main challenges for years, this article aims to investigate how contemporary model checking research approaches this challenge. Therefore, the article contains a structured literature review to map out methodical approaches and the use of empirical data from the industry practices to highlight how the research domain interacts with the problems situated in the practices. The study presents a review of 71 papers that shows the limited use of data from practice and a clear methodical trend of using artefact development with limited evaluation of empirical data from practice. These findings indicate a gap in the research domain of representing practice in model checking research.

18

Evaluating Four Types of Data Parsing Methods for Machine Learning Integration from Building Information Models

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A method and structure for architectural datasets specifically designed for the analysis, sorting, and ultimately reusing of building elements is proposed. Four different methods of parsing data from real-life projects using their building information models (BIM) for integration into a machine learning (ML) model were evaluated. As ML integration is becoming more important in the Architectural Engineering and Construction (AEC) industry, we see an increasing demand for high quality datasets. Four different methods and file formats were benchmarked, focusing on read and write-speeds for converting architectural BIM into datasets to be used in ML. Our results show that the current way of storing our projects in Industry Foundation Classes (IFC) is not optimal for the development and integration of new Artificial Intelligence (AI) assisted tools. This paper provides alternative methods and storage solutions for both developing new datasets inter-nally and also for future work in creating a common federated learning setting for the AEC industry.

21

Agile implementation for BIM education. Role of the human factor to create Scrum teams.

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Current construction industry tends to use frameworks in complex environments, with more variable scopes, less clear requirements, and more complex technology to solve them. Agile management systems can adapt the work of teams to these environments as a fast and flexible response to succeed, but the human factor is co-responsible for some of the difficulties that disruptive approaches can bring into our sector due to its resistance to change when there is a lack of understanding and a big impact by predictive management mindset. This uncommon case study of BIM Management training and its Master`s Final Thesis (Zigurat, Barcelona University, 2019) include a successful pioneering example in the university in which students are organised by teams according to Agile methodology and work using the SCRUM and Kanban frameworks with multidisciplinary and collaborative project-based learning, extracting a proposal for addition including principles already evaluated in previous studies. Final Thesis is a simulation of an integrated building project lifecycle, focused on client's value expectation, openBIM framework, a delivery strategy based on iteration and product increment. Scrum implementation, including the mentor as a client, has provided a high alignment between the expected value and the openBIM-based product delivery. This new strategy offers innovative tools to the student group, enabling collaborative and interdisciplinary work that fits perfectly with the BIM methodology. Therefore, this study reveals the need to include agile frameworks in the curricula, facilitating its transversal integration, without requiring major changes in the teaching plans and providing great advantages for the future of our industry, enabling the participation of professionals trained in agile environments and allowing to accelerate the digital transformation of this industry. This will happen because professionals that have learned to work from a different perspective, self-organized, multidisciplinary teams under a Scrum framework and Lean philosophy.

26

Multi-view KPConv For Enhanced 3D Point Cloud

Semantic Segmentation Using Multi-Modal Fusion With 2D Images

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Compared with unimodal deep learning algorithms that directly process 3D point clouds, multimodal fusion algorithms that leverage 2D images as supplementary information have performance advantages. In this work, the performance of an open-source multimodal algorithm, MVPNet, is improved on the 3D semantic segmentation task by using KPConv as a more robust 3D backbone. Different modules of the two networks are meaningfully combined: the 2D-3D lifting method provided by MVPNet aggregates selected 2D image features into 3D point clouds, then KPConv is used to fuse these features with geometric information to make predictions. On a ScanNet sub dataset, the proposed network significantly outperforms the original MVPNet and KPConv regardless of the fusion structure. By integrating COLMAP into the workflow, we further extend the proposed method to a custom dataset. The results show the improved performance of our multimodal fusion algorithm in identifying relevant categories of objects in the 3D scene.

28

Leveraging text mining and network analysis for a semi-automated work order process analytics

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Work order (WO) processing is a basic function of facilities management (FM). WOs are usually captured using computerized maintenance and management systems (CMMS) and contain valuable information about the performance of a building. They provide a very direct pathway to understanding the experiences of different building users and managers. However, given that this knowledge is in the form of unstructured text, the knowledge has remained vastly untapped. There are critical gaps related to the process of handling a WO. Each WO requires the communication of several people to make decisions such as, how urgent the order is, who is responsible for the task, and how much budget should be allocated for dealing with it. Given that the CMMS systems are not inherently designed for streamlining such communications, several challenges may occur during the decision-making processes. For instance, the task might be assigned to the wrong person, or its urgency might be evaluated incorrectly. This research will use the case of the university of Toronto to review key challenges during the process of handling a WO. Next, the research will discuss how text mining, network analysis, and machine learning can help automate WO process analytics. The results show that automating the WO process analytics can significantly improve FM by providing managers with insights about the key pain points and bottlenecks during the everyday management operations.

29

Can Traditional Delivery Model Still Fit in BIM Procurement? A Case of NZ Local Government

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Building Information Modelling (BIM) has evolved into one of the most promising technologies used in the architecture, engineering and construction (AEC) industry. However, despite the potentials, BIM implementation in the operation stage is slow, and its adoption in the local government sector for asset management is absent. The lack of BIM specific procurement methodologies is identified as one of the key factors in the unique governmental environment. Although various procurement methods, such as the Integrated Project Delivery (IPD) model, have gained significant attention and notable success in BIM based construction projects; however, these models are predominately project delivery focused and have limitations when used as the service delivery models. In the meantime, the traditional procurement models, such as design-bid-build (DBB), still dominate the public sector for a wide range of product and service procurement, given the low requirements for skills, experience, and business know-how within the clients' project staff. Through a case study of a local government in New Zealand, this research examines the traditional models and explores their opportunities to be used in delivering BIM-based services such as asset management planning. By introducing a staged and consensus based tendering method in the DBB model, this study helps to ease the obstacles of using traditional procurement methods in BIM service procurement by enhancing the collaboration between the client and bidders during the tendering process, thus accelerating the proliferation of BIM adoption in the local government asset management sector.

32

Extending ICDD Implementation to a Dynamic Multimodel Framework

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This paper targets the development of a dynamic multimodel framework that can facilitate BIM based fire protection and evacuation planning and training. It is inspired by the EU project BEST, which develops a novel real time hazard and evacuation simulation system and integrates three models, namely CFD simulation, crowd simulation and dynamic building model. The latter provides comprehensive information about the building, but this information is static and represents the building in an idealized state where no changes are happening over time. In current practice, the building model is input to simulation tools as a static model. We propose an ontological framework extending the standard ICDD implementation (ISO 21597) to a dynamic Multimodel Framework aiming to explicitly allocate multiple dynamic values to elements in the building mod-el. This enables consideration of dynamically changeable building elements' status at simulation runtime and hence real-time interoperability of the interlinked simulation components and modules.

33

Information Management when using BIM: Benefits and Challenges of Mobilisation

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Information management (IM) is a key determinant for effective Building Information Modelling (BIM) implementation. One of the important stages of traditional projects is mobilization, however, studies on IM mo-bilisation using BIM are rare in the literature. This study aims to understand the benefits and challenges of IM mobilisation activities in UK construction projects using a mixed-method research strategy. The findings indi-cate numerous benefits of implementing IM using BIM; however, the results reveal the limitation of IM appli-cation due to challenges and barriers that can significantly impact project performance efficiency. The study is one of the first to explore the role of mobilisation in IM when using BIM.

34

A BIM-based disaster response platform: Facilitating indoor path planning for first responders, UAVs, and UGVs

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During path planning, rescue operations in buildings are often hindered due to the lack of critical building in-formation. This paper proposes a real-time navigational platform combining various information sources to mit-igate this problem. Various operating agents such as first-responders and UGVs receive specialized assistance by integrating semantic information from digital building models with incident-related real-time data. The proposed methodology includes three steps: (1) Pre-configuration of conditions influencing path choices ac-cording to agents' capabilities and safety preferences. (2) Representation of the building geometry using a nav-igation graph. Inclusion of semantic information by weighting the graph with incident-related information, compared with the conditions per agent type and semantic information from the digital model. (3) Develop-ment of a knowledge database containing conditions for various types of agents. Evaluation in a real-world scenario revealed that paths calculated by the planning module were faster, shorter, and safer than those de-termined by first responders

36

Understanding "resistance to change" for organizational BIM adoption and new research ways forward

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The most cited barrier to Building Information Modeling (BIM) is resistance to change. By understanding the mechanism of resistance to change, possible practical recommendations and further research steps in BIM im-plementation can be identified. We explore the meaning of the resistance to change in the context of organiza-tional BIM adoption in the architecture, engineering, and construction (AEC) industry. We conduct semi-structured interviews with stakeholders in German AEC projects. The collected data was analyzed using the-matic analysis contextualized by a sociotechnical approach. The findings describe the most significant compo-nents of organizational resistance to change and their relations to each other. Having studied the phenomenon, we have identified the key enablers for dealing with organizational resistance to BIM adoption. Following a sociotechnical trend in BIM adoption research, we provide further in-depth understanding of the most cited barrier to BIM. We recommend BIM implementation plans address specifically resistance to change.

38

Digital twinning of existing bridges from point cloud data through deep learning on parametric models

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The Digital Twin (DT) of a bridge is a geometric-semantic model that supports and facilitates the operation and maintenance process of the structure. For existing structures, the semantically enriched 3D model of the DT is typically created by processing point cloud data (PCD). Semantic segmentation and para- metric modeling are two essential but laborious steps in the digital twinning of bridges. This paper contributes to automating these steps by applying deep learning and metaheuristic algorithms. Semantic features of points are extracted, and a deep learning model is trained. Subsequently, the segmented parts are parametrically modeled by applying a metaheuristic algorithm for model fitting. The presented results show that the DT of bridges can be created with a mean intersection over union (mIoU) of 88.45% and mean accuracy (mAcc) of 95.62% in semantic segmentation, as well as a mean absolute error (MAE) of 4 cm/m in parametric modeling.

39

Occupancy Assessment for Lighting Evaluation using Digital Twin technology

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The amount of information on evidence-based design in lighting is mounting, however the facility managers, lighting designers, and researchers are struggling with an implementation of an efficient post-occupancy evaluation system. This research aims to establish a method for Digital Occupancy Assessment for Lighting Evaluation (DOALE) to strengthen evidence-based lighting research supporting value generation for stakeholders. A prototype has been implemented using Azure Digital Twin and the RealEstateCore ontology to investigate how an ontology and a commercial platform, developed to facilitate data integration for smart buildings, can be used for occupancy assessment. The prototype was evaluated using a post occupancy evalua-tion session where data concerning environmental factors (temperature, illuminance) and data concerning oc-cupants (motion, galvanic skin response, and heart rate) were gathered. Questionnaires concerning occupancy perception were also carried out using mobile technology. Several interviews/discussions were also conducted with the lighting researchers using the prototype to perform the POE. The result indicates that it is possible to use current commercial digital twin technology to implement a post-occupancy evaluation system, but the technology is at present so complex that it is hard for a lighting researcher to adopt the system.

40

Enriching BIM-based Construction Schedules with Semantic Information using BPMN and LBD

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BIM-based construction scheduling is becoming increasingly important in research and practice due to the availability of the appropriate tools. However, it is characterized by a low level of detail and a lack of semantics, which is why the contained knowledge is hardly used for further analyses. Linked Building Data (LBD) is an intensively studied topic in construction information management, while the potentials and applications of LBD in BIM-based scheduling are still little investigated. LBD reveals new possibilities for improving semantic relationships between ontologies and enables the creation of knowledge graphs of BIM-based schedules for in-depth analysis. This paper investigates the enrichment of BIM-based scheduling with semantic information through formalizing schedules with BPMN 2.0 and converting and integrating process models into an RDF-based data structure in ICDD information containers. The integrated process knowledge can be queried via the SPARQL query language, allowing for extensible analysis and supporting decision-making processes.

41

The use of HBIM and scanning in cultural heritage projects

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The adaptation of HBIM, (Historic Building Information Modelling), in cultural heritage has been a challenge since such buildings are unique. This paper has, therefore, chosen to take a closer look at digitization and how it affects work in historic buildings. The purpose is to see to what extent HBIM has an impact on productivity in a construction process and whether this simplifies or complicates the work. A case study of the ongoing re-habilitation work at the old hospital building in Drøbak, Norway, was chosen. The shape of the building was collected by 3D laser scanning technology. The study also included qualitative in-depth interviews with a se-lection of involved actors. The interviewees had different roles in the project, which gave informative results and a broader perspective. In addition to this, a search in scientific literature was carried out in which relevant research and theories were analyzed.

42

How can LCA inform the early-stage design to meet Danish regulations? The sustainability opportunity metric

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The National Strategy for Sustainable Construction in Denmark (in 2021) has agreed to include new requirements in which the building environmental impact calculation will become mandatory. We present a general decision-support system framework that delivers LCA information on highly uncertain early-stage designs, aimed at architects and architect engineers. Our key contribution is that we define a new sustainability oppor-tunity metric assigned to early-design BIM model components. Our metric identifies sustainability opportunity "hot spots" (opportunities and risks) based on rapidly envisioning and qualitatively evaluating tens to hun-dreds of "what if" scenarios that account for early-stage design uncertainty. A prototype demonstrates two visualizations of our metric on two BIM models.

43

Life cycle potentials and improvement opportunities as guidance for early-stage design decisions

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Fundamental planning decisions made early in the design process have significant impact on the final building's performance. Computer-assisted approaches can currently only help in a limited way during these critical and recurring phases of design variants generation, assessment, and further elaboration. We investigate the concept of potentials and how it can support a digitally-aided design process. In this project potential is defined as the development possibilities of design variants or variant branches taking into consideration different evaluation criteria. These potentials serve as a link between the early stages of design and prospective future outcomes. To demonstrate potentials and their implementation we use life-cycle assessment (LCA). A real-world case study demonstrates the process of designing and detailing with guidance from potentials and improvement opportunities via a graphically laid out selective decision tree. This method helps designers locate areas with the greatest impact, communicate them to stakeholders, and make more informed design decisions.

46

Legacy practices to boost innovation processes using a Portuguese case study

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Building Information Modelling is being increasingly adopted by countries and it is recognized that its implementation demands changes, supplementary effort from stakeholders and alignment with existing practices. Countries that are behind can benefit from the trajectory made by others. Quick-wins can be achieved taking advantage of the existing documentation as well as legacy practices relevant for BIM adoption. This consti-tutes the aim of research work developed, where a mix of methods, ranging from the initial development work to surveys and audits, is applied to identify and deliver relevant lessons that are already part of the Portuguese construction sector and that overlap the requirements set by ISO 19650. The terminology is different but these correspond in terms of the principles and implementation. With this it is meant to support stakeholders on their BIM adoption route either faster or with less risks of failure

47

What Comes First when implementing Product Data Templates? A Portuguese social housing refurbishment case study

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A built entity is composed of different construction products and its data digitalization is found to be crucial. However, this is a highly complex task due to stakeholders' wide range of solutions and requirements. The ability to identify the most relevant Data Templates (DT) is key to set meaningful steps for the value-chain in-novation. This work contribution is the development of a case study using a Portuguese social housing build-ing representing the stock to be refurbished under EU Renovation Wave. Findings indicate that relevant con-struction and deconstruction activities address elements as windows, roofs and doors. When targeting decon-struction activities, hazardousness and waste analysis are crucial vectors for product digitalization. On the other hand, when targeting construction activities, key aspects to evaluate are the energy efficiency index and facility management. Products BIM dimensionality, detail and layers are crucial elements for both types of ac-tivities for DT cases implementation.

49

GreenBIM - fundamentals for the integration of building greening in openBIM projects.

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Due to urban overheating, building greening systems are becoming more important. Models of greening systems will thus play an important role in future openBIM-based planning processes. However, open exchange formats such as IFC do not yet include attributes for such systems. To close this gap, the required attributes to describe building greening were developed by a multidisciplinary team of specialists. Necessary attributes were determined based on norms, standards and experience from pilot projects. Moreover, the attributes were equipped with project phase information and responsibilities. The identified attributes were structured in agreement with the IFC data structure and implemented in a BIM data management platform. The comparison of the identified greening attributes with the IFC standard has shown gaps in the IFC standard. It is thus important to enhance the IFC standard and the bSDD. This enhancement would bring benefits for project stakeholders in the implementation of openBIM projects.

51

Visual Programming into BIM environments: a simulative framework to evaluate constructability through parameter optimization at early design stage.

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BACKGROUND AND IDENTIFICATION OF PROBLEM: Digital project on heritage are more complex because they need to use several tools to manage existing geometries and material properties. Thus, construction projects are becoming progressively larger and more complex in terms of time and cost, because of the higher level of satisfaction of rules. In this context, there is a lack of collaboration among design phase and construction management sector. Construction phase consideration and improvement strategies rarely influence choices made in design phase, and consequently 4D and 5D analysis rarely influence design choices. RESEARCH AIM AND METHODOLOGY: The aim of the research is to develop a methodology capable of providing designers a real time simulation of optimized construction solution. To reach this result, a combined algorithm of structural solution, construction difficulties and performance is developed. This collaborative procedure is capable of checking in real time the feasibility of design solution in structural and constructional terms. We describe a framework of the different tools involved. Finally, an experiment on an actual construction site is conducted. RESEARCH FINDINGS AND CONCLUSION: During construction phase, the results expected in simulations were highly confirmed. It confirmed simulation process as a reliable way to predict unexpected situation, mostly during construction phase. So, we show how it could be preferable that design editor like BIM-based tools provide designers plug-in concerning construction evaluation of selected choice. Involve construction aspects into early design phases will clearly reduce errors and reworking.

54

Facilitating practical BIM-based FM: Development process, conceptual design, feature- and software requirements"

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The use of BIM – Building Information Modeling - is emerging in building projects all over the world in the Architecture/Engineering/Construction (AEC) field. Further, BIM was always meant to be the lifecycle-oriented technology around all building matters including the operations phase. Building operations are handled by FM – Facility Management - and its technological foundation in practice is called CAFM - Computer Aided Facility Management. Although FM works fundamentally rely on building information and BIM is also widely accepted as an advantageous source of building information for CAFM, BIM-based (CA)FM is still not in general use in practice - not to speak of the adoption of openBIM-based FM which suits the long(er)-term challenges of FM. One commonly stated reason for the discrepancy is that the work disciplines are historically too much apart in language, scope, and goals of work with building information. This paper shows findings about conceptual design and feature-requirements of BIM-based FM systems conforming to openBIM standards and ISO19650's life-cycle paradigm based on a research backed, real-world case study for the development process to facilitate interdisciplinary understanding and compatible technology.

55

A ontology-based experty system for quality inspection planning in the construction execution

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Poor quality is one of the biggest challenges for the construction industry. Most deficiencies occur in the construction process and could be minimized by improved and continuous quality control. For this reason, this paper addresses how to improve the planning of quality inspections in construction. The focus is on the automated planning of inspections. The preceding literature review has shown that previous works neglect the planning of quality controls and focus on the recording as well as the evaluation of qualities. The following study shows that ontology-based expert systems are able to plan project-related quality inspections for a mutual control of trades. The developed rule-based system allows an automated planning of quality controls by shapes constraint language rules. The automated planning eliminates monotonous planning tasks and enables site managers and supervisors to perform systematized inspections on the construction site.

57

Automated Floorplan Generation using Mathematical Optimization

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This paper presents a tool for automated floorplan generation by using mathematical optimization. The floorplan generation is transferred into an optimization problem, the building outlines and the rooms are parametrized as axis-aligned polygons and rectangles, and the requirements for the size, position and adjacency of each room are formulated as constraints in the optimization. The model is built as a mix-integer nonlinear programming and can be solved by a mathematical programing solver. In the presented paper, a tool is introduced for defining the input requirements, performing the floorplan layouts and exporting the results as an IFC model which can be further processed in openBIM compatible tools. The result shows that the developed optimization model fulfills the requirements of a room book and provides appropriate floorplan proposals.

58

A Novel BIM Platform Paradigm for The Building Performance Domain

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Although Building Information Modelling (BIM) promised a new collaborative work paradigm for the AEC disciplines, current workflows in the AEC sector are still sequential, fragmented, and served by diverse software, especially in the building performance disciplines. The building performance domain has multiple native performance models and data schemas from a wide variety of simulation tools, which leads to incompatible, incomplete, or redundant information and the need for rework in the current performance analysis workflows. A new paradigm is needed, in which performance domain analytical models can be prepared automatically from a database system that can also check for and maintain consistency, accuracy, and completeness within and across federated building models. This paper describes a BIM platform consisting of a holistic ontological framework for building performance modeling with cloud and semantic web technologies and founded on a knowledge-graph-driven database management system. It describes a future state-of-the-art configuration de-signed to address these challenges. It also outlines the suggested method and the potential workflow benefits in the AEC sector. The paradigm design is intended for software vendors, who can apply its principles to de-velop new generation software programs in the future.

59

Same same, but different – or how BIM is taught in Norwegian and Swedish universities

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In response to the increasing demand for construction informatics (CI) expertise, universities in the Nordic countries have developed new educational offers. This study explores how CI related education is being delivered by three different universities, two in Norway and one in Sweden. By comparing curricula and interviewing CI teachers, this paper contributes to the recent debate on the international standardization of CI competence by providing a Scandinavian view. The paper uses a pedagogical framework for hybrid teaching identifying which different "Scandinavian" aspects of CI-based work are focused on education. The results illustrate how all universities provide core competencies for digital work in projects, but their emphasis differs. What all CI education, sampled in this paper, had in common is a strong emphasis on the socio-technical aspects of CI as well the hands-on technical aspects of BIM. It can be reasonably claimed that a more Scandinavian approach to CI education could further inform the standardization of BIM competence. Moreover, this integrated approach appears well suited for creating student engagement and for turning construction into a modern sector of the economy.

60

A framework for meta-disciplinary building analysis

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Designing sustainable buildings requires the orchestration of analysis processes throughout a building's lifecycle. The siloing of disciplinary knowledge, tools and processes can mean that analysis is wastefully repeated or omitted in siloed disciplinary models and data. Therefore, this paper proposes a framework for meta-disciplinary building analysis consisting of three modules: (1) common building elements for building analysis; (2) the analytical needs of different disciplines, and finally; (3) computational approaches that could be applied to provide this analysis. Finally, a methodology of analytic moves is presented to explore the framework and identify potential future work.

63

A BIM-based workflow to configure construction processes for a modular robot system

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With the accelerated pace of social and economic development in recent years, the importance of robotics has become increasingly prominent. Current approaches mainly consider robots as helping tools either that are fully piloted by humans or only that process simple, repetitive tasks. That is because robots are often designed for a limited number of tasks and are inflexible for more complex tasks that exceed their functionality. However, an appropriate configuration of the utilized robot components and workflows of subtasks requires a deep understanding of building structures, as well as the robot system and general knowledge about related construction processes. For modeling and accessing information of built artefacts but also of activities executed on them, the methodology of Building Information Modeling (BIM) is well suited. This paper proposes a concept for generating a workflow for a modular robotic system from a BIM model, including component configurations for the robot as well as other resources or information required for the construction of building elements. A database containing reference processes and an information repository for robot components is utilized as a support.

64

SmartBuilt4EU: towards a strategic research and policy agenda for the European Smart Buildings Community

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Buildings are on the way to transform from passive isolated elements to smart buildings, able to adapt to occupants needs and behave as active nodes, integrated to the energy grids and other infrastructures. The potential of smart technologies in the building sector was heavily emphasised in the 2018 revision of the European Energy Performance of Buildings Directive (EPBD) and the creation of the Smart Readiness Indicator concept. While technologies are available to increase buildings' smartness and the related benefits, numerous challenges remain to ensure their societal and regulatory adoption as well as their technical integration within building and into relevant services. The European project SmartBuilt4EU, aims to foster collaboration be-tween stakeholders of the smart building innovation community in order to address such remaining challenges. The Task Forces set up by the project gather a variety of stakeholders within this community and aiming to address in a collective manner some specific topics related to smart buildings that require further investigation to enable their full uptake. This paper synthesizes the first topics investigated by the Task Forces: 1) End-users acceptance and attractiveness; 2) Interoperability; 3) Providing flexibility to electricity grids; 4) Business models and smart financing. It presents the key questions tackled by each Task Force, the barriers and drivers detected in relation to each topic, and the resulting research and innovation gaps identified.

65

Inferring Interconnections of Construction Drawings for Bridges Using Deep Learning-based Methods

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The availability of digital models of existing structures plays a vital role in leveraging the full potential of digital planning methods like building information modeling (BIM) in the building's operation and maintenance phase. Since BIM models are, however, widely unavailable, the reconstruction process must be carried out in advance. It is particularly tedious for engineers to reconstruct 3D models from drawings, since many partial views are included, e.g., sections. Consequently, the interconnections between the views must be established before reconstructing the geometry. This research proposes a deep learning-based method to localize section symbols on construction drawings and recognize their associated denotations. Also, the title of the view is recognized to derive the respective connections between the section symbol and the corresponding view. The proposed pipeline is tested on actual bridge drawings and shows promising results. This paves the way for future works addressing the automatic reconstruction of the bridge geometry.

67

Systematic Investigation of Interoperability Issues Between BIM and BEM

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The lack of proper interoperability creates concerns about the integrity and reliability of transferred data information when integrating two or more digital systems. It is significantly hindering the Building Information Modelling and Building Energy Modeling integration at the primary level and slowing down the realization of construction4.0 initiatives at a large scale. Many efforts have been performed by academia and industry practitioners to solve this problem. However, they either rely on openBIM schemas for data transfer or create semi-automated yet unidirectional data mapping solutions aiming at helping the seamless flow of information. They usually suggested several solutions to improve interoperability at the end of their efforts, including using the same company tools or enriching the semantic information during the early BIM modeling stages. The interoperability dilemma remains a challenge even in the present digital construction industry. Besides, a critical assessment of currently available interoperability solutions for viability, workability, and reliability is undoubtedly another puzzle. Therefore, this research systematically investigates BIM to BEM interoperability issues and corresponding solutions and provides a comprehensive outlook of the functional interoperability solutions. Authors applied available interoperability solutions at the related processes, for instance, BIM modeling, BIM-based energy modeling, data transfer, and energy simulations, in conjunction with widely adopted BIM and BEM modeling programs. More than ten case studies support the investigation of interoperability solutions, including geometrical information, construction processes and materials, spatial data, thermal zones, MEP systems, and occupancy usage assumptions. A comparative assessment of interoperability solutions has revealed that although it is tedious and time-consuming to include interoperability solutions during the BIM modeling process, it produces significantly better energy simulation results. In general, having an automated and bidirectional methodology of seamless information flow between BIM to BEM can provide a standardized process and a promising tool for stakeholders to achieve sustainable and low-energy goals.

68

Using RASE to represent normative, definitive and descriptive knowledge.

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The RASE methodology has gained some attention as a means to expose the logical objectives and individual metrics found in regulatory and contractual documents. This paper will explore the role of RASE in exposing not only normative documents but also both definitive resources such as dictionaries, thesauri and classifica-tion tables, and descriptive resources such as BIM models, contract diaries, product data or technical journal-ism. A single common execution framework allows any of these resources to be cross-compared, independ-ent of domain or language. This support for mixed modalities opens the potential for RASE to be used as a core concept across multiple domains and information types.

69

Challenges and experiences with the reuse of products in building design

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Over a third of greenhouse gases emitted in Europe is related to buildings. The upfront embodied emissions from construction and manufacturing of building materials represent a third of that. One way of limiting those emissions is to reuse already produced building components before downcycling them. However, this is not a common practice. The study comprises twelve semi-structured interviews with mainly Norwegian industry representatives and experts to answer the question: what is the attitude towards the reuse of building components among those who largely influence design decisions? In the paper, we describe how consecutive design with used elements differs from initial design and what challenges it entails. Among the interviewee's reflections are the importance of design time and convenience, higher costs of consecutive design, lack of long-term thinking among clients and designers, and challenges with managing information about potentially reusable elements. Presented research adds to the body of knowledge on reuse barriers and opportunities with new, previously uncaptured perspectives. It can be helpful for understanding designers' needs and seeking solutions to popularize material reuse.

72

Structure- and LCA-driven building design support in early phases using knowledge-based methods and domain knowledge

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Early planning decisions highly influence the resource-efficiency and environmental impact of a building design. Through the inclusion of design knowledge regarding the structural design and embedded emissions, the design process can be effectively supported. For the early provision of the multidisciplinary knowledge and a related design assistance, the application of knowledge-based methods is proposed. Based on this approach, an expertise regarding the structural design and material-related embedded emissions is provided in the form of easy-to-understand design information. An achievable design support is demonstrated with the aid of a case study on a real-life building design. In this context, the early inclusion of knowledge enables a promising multidisciplinary design assistance regarding the structural and environmental performance. Through extension of the involved knowledge, the application range of the design support can be enlarged. For this purpose, the application and inclusion of further knowledge sources are addressed in future research.

73

Consideration of detailing in the graph-based retrieval of design variants

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During early design processes, interdisciplinary experts frequently exchange building information at different Levels of Development to generate designs fulfilling multiple requirements, by ideally using building information models. This paper presents an opportunity for architects to gather inspirations for upcoming projects based on previous designs and knowledge in relation to the detailing of building elements. For this purpose, two approaches from the research group FOR 2363 are combined. Initially, this refers to the variant management, which enables to find and compare multiple similar design options to an existing building structure, through a subsequent retrieval process. The second research focuses on the detailing of components and potential uncertainties associated with geometric and semantic information. Regulations for unifying these approaches are formulated and the similarity calculation is specified. This leads to an optimization of the retrieval process including the consideration of the detailing of components. The usability is afterwards demonstrated.

76

TwinGen: Advanced technologies to automatically generate digital twins for operation and maintenance of existing bridges

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The high effort of operating and maintaining existing infrastructure facilities resulted in a large stock of structurally deficient bridges in most industrialized countries. Today, the condition assessment of bridges is conducted mostly manually. To relieve effort and costs, the digitization and automation of conventional manual, labour-intensive methods is necessary. We interpret the ambiguously used term "digital twin" (DT) in this study as a semantic-geometric model of an existing asset (here, a bridge) that contains all information required for assessing its current condition. This paper proposes an approach to automatically generate the DT of existing bridges from point cloud data (PCD) and images captured from the structure. The PCD of the bridge is semantically segmented by means of ML techniques, and a digital model is created using parametric modeling. Subsequently, detected damages and data from existing bridge maintenance systems are linked to the model to create a full DT. This paper reports the main results of the TwinGen research project: The digital twinning process of bridges can be automated to a large extent, in order to efficiently support the maintenance process of bridges.

77

Model Healing: Toward a framework for automatic adaptation of building designs to achieve code compliance

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One of the prevailing practices across building and construction projects is to evaluate build- ing design against building regulations. When violations occur, architects and engineers analyze the involved elements and their characteristics and then iteratively revise the design, in an attempt to overcome those vio- lations. With the help of state-of-the-art code compliance checkers, practitioners currently interpret the results and then adjust the design manually based on their expertise. Currently, there is no methodology available to automatically connect the identification of compliance violations to solving the related design issues. To address this gap, a generalized framework, Model Healing, is introduced for automatically adjusting BIM models to overcome compliance issues. Design parameters associated with the target checking rules are considered adapt- able inputs for creating comparable design variants. To represent the conformance on checks and the difference to the original design, we define essential metric indices that support the searching toward Model Healing. Finally, valid design variants close to the initially investigated design are elected. The paper concludes with a case study indicating the applicability and current limitations of the proposed workflow. This framework will facilitate building design adjustments and error correction with higher efficiency.

78

How to represent damage data in BIM Models? A systematic literature review

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In the last decades, we faced paper to CAD (Computer-Aided Design) and CAD to BIM (Building Infor-mation Modeling) revolutions, which have changed the AECO (Architecture, Engineering, Construction and Operation) industry. Despite implementing CAD and BIM methodologies, the most efficient way of collect-ing data about defects and damages is still complex to define. Despite that, defects occurring in the AECO sector are responsible for the substantial increase of investment cost and impact on the schedule. The paper presents a review of the literature and discuss and compare available methods for damage data representa-tion in a broad scope of objects, such as bridges, buildings and tunnels. Diverse damage visualization and management are demonstrated to describe their characteristics, benefits and drawbacks. The main question is how to represent the damage data in BIM Models reliably and efficiently according to the required level of information. Various applications and approaches assigning damages to BIM components were demon-strated and discussed. Researchers explain various methods used to link defects with BIM among AECO professionals.

80

BIM adoption in small-scale infrastructure projects – investigation on the German railway sector

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Building Information Modeling (BIM) for infrastructure is gaining importance and is being investigated in several large-scale pilot projects. However, the research undertaken in large infrastructure projects reflects only part of the problems on the way to BIM comprehensive adoption. Moreover, the exclusive focus on project-related implementation does not provide insight into the organizational introduction of BIM. Our research aims to overcome these limitations. The study explores why and how public clients in the railway infrastructure sector adopt the BIM methodology for small-scale projects. For this purpose, we conducted a narrative literature review and a case study on the German railway sector (at DB Station & Service AG). The literature review on BIM adoption in infrastructure projects is followed by an investigation and analysis of 25 BIM workshops with infrastructure stakeholders executed by one of the authors as an external trainer. Our research shows how far BIM can be adopted in small-scale infrastructure projects and provides recommendations for further development.

81

Establishing A Digital Twin-enabled Smart Parking System Based on BIM and Computer Vision

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With the fast-paced global urbanisation, the population in major cities has grown significantly over the past decade and parking in urban areas has become a significant challenge worldwide. To address urban parking difficulties, a promising trend is to improve the use rate of existing parking facilities and help drivers understand the real-time and foreseeable utilisation. Existing efforts have focused on developing Internet of Things (IoT)-based parking monitoring solutions. However, they are limited to indoor environments since they require up-front pre-installation and regular maintenance; little is known about how to develop a practical and easy-to-use parking solution for outdoor, uncovered parking facilities. To address this knowledge gap, this paper presents a digital twin-enabled smart parking system based on Building Information Modelling (BIM) and computer vision (CV). The system can acquire real-time parking status with a developed CV-based object detection algorithm and integrate the spatial information of car parks through BIM to present the real-time parking status to users. To prove the concept of this study, a prototype of the proposed smart parking system has been developed and tested in a multi-bay car park. The proposed system provides an affordable solution for both vehicle drivers and car park owners. It offers convenient user experience by helping drivers identify available parking spaces around their destination. It also allows car park owners to monitor their properties in real-time easily.

82

Machine Learning and Genetic Algorithms for conformal geometries in design support systems

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To optimise both building designs and their underlying design processes, design support systems exist. For domain specific analyses, these systems benefit from a conformal (CF) representation for the Building Spatial Design (BSD). In a conformal representation, for all entities: the vertices of an entity are, if intersecting an-other entity, only allowed to coincide with this other entity's vertices. This paper presents research on whether Machine Learning (ML) and Genetic Algorithms (GA) can be used to obtain a conformal geometry for BSDs. For ML, a neural network is trained to learn the complex relation between BSDs and their conformal representations. GAs are first used to find all quad-hexahedrons in the search space, then to find sets of quad-hexahedrons that form the conformal design. A trained ML model does provide outcomes, but not very useful, even with encoding the configuration type of the design. Differently, the GA finds conformal designs for many instances, even for non-orthogonal designs.

83

Integrating Level(s) LCA in BIM: A tool for estimating LCA and cost impacts in design

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This research aims to tackle green inefficiencies using Building Information Modeling (BIM), particularly by developing an innovative Level(s) LCA plugin to estimate the building's environmental and cost impacts and thereby help decision-makers to account for the full Life Cycle (LC) of the building in the design phase.
The plugin provides a visual interface that shows both quantitative and graphical results of the impacts. The plugin was used in a case study of new construction dwelling to estimate the LC impacts for walls.
The main results show that the Level(s) LCA plugin is suitable to perform both environmental and economic analysis and can now be used in other design projects to anticipate and mitigate the impacts of the construction sector. The case study can be seen as a proof-of-concept that such an integration in BIM offers results of high relevance when in the search for ways to optimize the LC impact.

84

Process-based building permit review – a knowledge engineering approach

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Digitalization and applications of intelligent systems in the AEC sector increasingly demand data. Required data is often not accessible but necessarily needed to interpret information and finally to transform into knowledge. For this reason, suitable data must be collected, analyzed, and formalized, before data can be used to feed systems in regard to automation. In scientific practice, the problem of how data is to be conducted for knowledge representation appears frequently. Using the example of building permit reviews, this paper presents qualitative expert interviews as a convenient method in terms of knowledge engineering. Subsequently, obtained data is used to develop an ontology representing building permit authorities. The approach is validated by automating the subprocess of participation of agencies of public interest during the building permit review. The approach represents a solid method to generate data as well as demonstrates transferring knowledge in an ontology through rules and queries.

87

Reference process for the transformation of unstructured object catalogues into interconnected data dictionarys

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Sufficient data and precise digital information are the main requirements for all processes within the BIM methodology. To enable an effective exchange and usage of data throughout the life cycle of a building,
data catalogs and building codes provide centralized repositories using standardized definitions of building elements and properties. At present definitions for these elements and properties exist mostly in unstructured
non-machine-readable form. This information needs to be transferred into structured data catalogs to be able to
be used in the BIM process efficiently. To provide a structural basis to simplify exchange, interoperability, and
portability ISO 23386 was conducted. This paper aims to conceptualize and implement a k-means clustering algorithm using GermaNet to support the creation of groups of properties hierarchies according to ISO 23386.
Finally, the developed method is tested on different data catalogs and evaluated concerning its usability for the
desired use case.

90

Sustainability assessment of a novel reusable and demountable steel-concrete composite floor system

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Raw materials extraction, production of components, transportation and reverse logistics activities that run in the construction sector are constantly depleting the available global resources. Sustainability of the construction industry and its ability to adopt to the principles of circular economy is under question. This paper addresses these questions through the introduction of a novel reusable steel-concrete composite floor system. Its reuse potential is evaluated through comparative BIM-based Life Cycle Analysis with contemporary systems

98

Digital Twin in Healthcare Facilities: Linking Real-Time Air Quality Data to BIM

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In this paper, the authors provide an overview of what are Digital Twins (DT), why DTs provide advantages to facility management (FM) practices and how can a DT be implemented. Focusing on healthcare facilities, the paper defines how a DT implementation can support two broad areas in healthcare: facility maintenance and space management. A case study of an operating room (OR) is used to illustrate the implementation of a DT prototype. Realtime sensor data is linked to an OR BIM using Azure cloud services and Microsoft Power BI. An example dashboard is created in Power BI to demonstrate various visualization tools of Power BI and its interaction with live sensor data. The authors also reflect on how the system architecture proposed in this paper can reduce the complexity of creating a DT and how standardization in DT creation can support the scalability of the discussed DT prototype.

100

Management of BIM-based Digital Twins in Multimodels

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This paper presents the use of the Multimodel method for the management of digital twins (DT) in Building Information Modeling (BIM)-based virtual labs. The contents of the Multimodel are based on the software tools required for the specific application, whereby the DT is not a monolithic artifact, but a dynamic set of interlinked domain-specific technical models. The links are specified in machine-interpretable formats, such as the Resource Description Framework or the Web Ontology Language, and stored in separate link models. Additional semantic information, that is not part of the technical models, can thus be generated by inference mechanisms. This approach enables the automation of complex processes in cyber-physical systems and increases the robustness against human input errors. A prototypical service implementation and evaluation in a bridge monitoring application underpins the feasibility and benefits of the developed concept.

101

A Framework of Improved Interoperability for VGI3D Platform

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The VGI3D platform is a web-based interactive system for low-cost 3D building reconstruction. This platform balances the costs, the speed, and the reconstruction performance of constructing 3D building models. However, it lacks the support of complex building reconstruction and needs much user interaction to solve the model integrity problem. In this paper, a new conceptual framework with improved interoperability is proposed for VGI3D, to better reconstruct 3D building models. Multi-source data and façade grammars are considered in this new framework. The redesigned database to save façade semantic information can improve the interoperability of the information from multi-source data. The new updating method of façade grammars based on recursive neural networks can improve the interoperability between façade grammars. Furthermore, they can improve the information transmission during the process of 3D building reconstruction and support the VGI3D to better construct the 3D building models. The new version of VGI3D based on the new framework will be developed and released to public in the future to better support 3D building reconstruction.

103

BIM integrated data management for the operation and maintenance (O&M) of railway

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Regular railway inspection and maintenance generates massive amounts of data over time. The organization of these interrelated data is a challenging task considering the multiple sources, multiple purposes, and huge volume of data. Besides, the O&M phase of railway system involves different stakeholders that play a wide spectrum of roles and that requires close collaboration among them. We proposed a BIM (Building infor-mation modelling)-based data management and visualization platform that integrates multi-source data and serves multiple stockholders. The platform is able to realize the data tagging of on-site inspection and maintenance record, the processing of high-accuracy railway settlement data, the transmission of cloud stor-age data, and the real-time visualization in 3D railway map. Based on this platform, a substantial increase of the applicable interoperability will be achieved between different stakeholders and BIM platform.

104

Designing a framework for seamless integration of open data services to support disaster response

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With an increase to the availability of open data, the potential to leverage it for emergency response and disaster management has so far seen seldom use in Germany. While some modern technologies have found their place in existing workflows, open data and related services are rarely utilized. Due to varying standards and approaches in the federal system, public sector as well as community data sources often cannot be easily integrated. As such, an adaptable framework is proposed that outlines a way for practitioners to include these services via the OpenAPI specification without the need for programming or data science knowledge. Instead, the API documentation is parsed by an application offering various customization and configuration options during a mapping process enabling users to create their own interpretation of the data for beneficial use during disaster response efforts, resulting in a dashboard with map views and other visualizations.

105

An ontology-supported case-based reasoning approach for damage assessment

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Despite new technologies in machine vision allow for an automated damage detection, current practices in damage assessment rely mainly on manual evaluations by human experts. Although some new approaches propose a damage assessment via machine learning methods, essential contextual information about the damaged construction is not considered. Contrary to this, knowledge-based approaches have been researched. However, knowledge bases for damage assessment usually contain certain knowledge gaps that result in uncertainties, which still need to be solved manually by experts. Therefore, in this paper a new theoretical approach that utilizes case-based reasoning (CBR) is discussed as additional method for automated damage assessment, which could be utilized in conjunction with knowledge-based approaches. Thereby, the case base of the CBR system would be developed as ontology utilizing the Web Ontology Language (OWL) in order to be compatible with current knowledge-based approaches, especially the Damage Topology Ontology (DOT).

106

A-EYE Control Tower: An AI driven visibility platform to improve productivity on construction jobsites

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The authors present the early stages of an Irish government-funded project, A-EYE. This disruptive technology seeks to create a construction visualization platform that enables measurable productivity advantages through passive data capture and real-time delivery of mission-critical information in an accessible form. The authors outline how they will utilize data captured during construction site operations using camera and sensor equipment to monitor construction resources and processes. Moreover, the positive impact of easy access to visualized data on collaboration between construction stakeholders is discussed. Extensive user-experience research data will be captured after deploying the technology on live projects to create interactive dashboards that can co-exist with 4D BIM data leading to improved workflow and productivity on construction job sites. A-EYE promises an integrated and connected system bringing real-time reality capture and automated scheduling into a singular real-time data source.

107

OpenSantCugat: A platform for municipalities to integrate building energy information with public data

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Building-related data managed by municipalities are dispersed among city departments and supra-municipal administrations. The drawbacks of this dispersal are twofold: 1) It hinders the communication between city departments, and 2) It prevents citizens and companies from exploiting public data. We have developed OpenSantCugat, an open platform which integrates the data generated by municipal departments (e.g., building permits, facilities inspections, water consumption) and those provided by public bodies (e.g., energy certificates, cadastre, solar radiation maps) to facilitate data management within and across city departments, and to provide citizens and businesses with access to the public data they might need. The integrated data is provided by means of multi-layered maps, tables and reports, and aggregated at different scales (city, neighbourhood, block and building). The experience with the development of this open data platform confirms that municipalities need such tools to improve their work processes as well as to effectively promote open governance.

109

Effective use of inverse relation attributes in IFC

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Whenever applications process exchange structures in IFC format for analyses and updates during data exchange, they rely on efficient navigation. For inverse relation attributes, these applications need to make a trade-off between time and space complexity for the decision whether to maintain inverses explicitly or to evaluate them dynamically as needed. This work uses a graph representation to analyze the IFC schema, a range of IFC instances, and an implementing application to support this implementation decision.

110

Predicting semantic building information (BIM) with Recurrent Neural Networks

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Recent advances in technology established artificial intelligence (AI) as a crucial domain of computer science for industry, research and everyday life. Even though computer-aided architectural design (CAAD) and digital semantic building models (BIM) are essential aspects of the contemporary architectural design process, the acquisition of proper data proves challenging and AI methods are absent in established design software. An option to acquire rich data are design protocol studies sequenced through meaningful relations. However, this data requires a framework for pre-processing and training artificial neural networks (ANN). In this paper, we present our research on BIM and AI for autocompletion through suggesting further design steps to improve the design process of the early design stages, based on the methods of the 'metis' projects. We propose a recurrent neural network (RNN) model to predict future design phases through sequential learning of cognitive sequences, utilising enriched sketch protocol data.

111

Towards a semantic enriching framework for visual understanding of construction site images

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Recent applications of deep learning (DL)-based methods in construction have achieved notable momentum in making the construction management process smarter. The deployment of DL-based visual analytics systems is not only aimed at reducing manual efforts in data collection and analysis but also needs to semantically enrich the original visual resources to improve situation awareness and scene understanding of the construction process. This paper proposes a semantic enriching framework that integrates consolidated DL technologies with prior domain knowledge to prompt a traceable, explainable high-level information inferring process to explore semantic information behind visual resources collected from construction sites. The introduced framework starts from feature extraction from multiple aspects, thanks to the support of DL algorithms; then transforms the acquired facts into ontological assertions to iteratively reach higher-level interpretations achieved by semantic reasoning and querying. A case study, which manually grounds the primitive facts of a site image and manually simulates the reasoning process based on the collected facts, is carried out to demonstrate the feasibility of the proposed framework.

114

A strategic roadmap for the development of digital platforms in construction: The DigiPLACE Strategic Roadmap

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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. 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 presents the DigiPLACE strategic roadmap starting. It has been developed as a seven-years program organized around four main topics. The roadmap highlights a multilevel structure that sees the integration of the efforts at different levels to create a digital ecosystem for construction sector.

121

Extending the IFC-Standard for fire safety building permit

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The increasing application of Building Information Modeling (BIM) is brought in the decision making of the planning and construction for more and more projects in the AEC/ FMindustry.All these pro-jectshave toconsider the fire safetyrequirements to ensure the safety goals of thebuilding code. Consequent-ly, thereis a need for a standard and formal definition of fire safety information in BIM. The goal of this pa-per is to extend the IFC specificationsfor fire safetycomponents. This paper shows the results of the analysedrequirements and existing IFC schema in terms of firesafety, limited to the use case and regulations in Ger-many. Based on an assessment of this analyses, this study determinesthe missing informationrequirements of fire safetyin the BIM environment and defines new entities and properties. However, there are a wide range of required entities and properties that haveto be added to the BIM standard. The authors expect to improve the process of BIM quality assurance and enhancethe quality of BIM informationwith this researchon fire safety.

122

Predicting the Construction Duration in the Predesign Phase with Decision Trees

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This paper analyses how well decision trees (DTs) predict the construction duration in the predesign phase. To answer this question, the authors first evaluate the expected prediction accuracy with a survey in the German AEC industry. Second, they compare the prediction accuracy of five DTs (Random Forest, GBR, XGBoost, LightGBM and CatBoost) with artificial neural networks (ANN) and linear regression models (LRMs) in two exemplary data sets from residential projects. The study uses performance indicators mean absolute error (MAE) and mean absolute percentage error (MAPE) as metrics. The results reveal that DTs perform better, with the underlying data sets, than ANNs and LRMs. The expected prediction accuracy of 26% is fulfilled in data set 1 with a MAPE of 13.48% and is nearly reached in data set 2 with a 26.45% MAPE. This shows the potential of using DTs in practice as more and more data in construction is generated. From a practical perspective, the explainability of DTs should be further tested in predicting the construction duration.

123

Semantic Enrichment of Object Associations Across Federated BIM Semantic Graphs in a Common Data Environment

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Explicit association semantics across federated BIM models facilitate the interoperability between design systems and open opportunities for intelligent applications. However, the automated inference and generation of such semantics remains a key challenge. Graph representations of BIM models have shown potential in supporting semantic enrichment and conveying formal building semantics across domains. In this paper, we present our implementation of a semantically-enriched Common Data Environment – the Graph-based Core-extension Data Framework – composed of a semantic graph layer and an object geometry extension layer, hosting the heterogeneous information from BIM models. A novel rule-based inferencing approach, the TIOC algorithm, was implemented on the federated building representations to infer and establish inter-domain topological and correspondence relationships, interconnecting disjoint domain specific graphs with meaningful formal semantics. This study is the first known attempt to implement a semantic enrichment algorithm for implicit object associations in the context of multidisciplinary models.

124

Artificially Intelligent Classification of Structural Plans for Automated Schematic Design of Reinforced Concrete Structures

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Despite significant developments in the field of computing in construction, schematic engineering design – such as creating structural layouts based on architectural models – lags technologically. Schematic design is still manual and based on rules of thumb and experience. This stage is the most important and creative stage in the design process of buildings and greatly affects the final engineering solution. Even after rigorous analysis, a non-optimal initial design will often lead to a suboptimal structure.
In the construction industry, there are still relatively few applications that use artificial intelligence (AI) in the initial design phase. An advantage of AI is the ability to learn procedures from data describing cases. For example, using machine learning, it should be possible to receive as input many structural models, designed by engineers, and to learn how to generate and to evaluate new building designs. Thus, it should be possible to simulate the experience of engineers accumulated over years of practice. In this study, we aim to illustrate this idea by devising an artificially intelligent application capable of performing initial design of structures, in a fashion similar to, and perhaps even better than that of human engineers.

125

International assessment of Artificial Intelligence applications offered in the AEC industry

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The construction industry suffers from productivity stagnation and slow digitalization. Its digital landscape is characterized by substantial data heterogeneity and project-specific data silos. To address these challenges, a growing number of tech-companies are developing applications based on Artificial Intelligence (AI). AI can analyze complex data structures and help automate tasks and support decision making. This study aims to identify gaps and opportunities in the industry's adoption of this technology. A set of 16 variables was used to characterize 236 tech-companies offering AI solutions for Architecture, Engineering and Construction (AEC). Their potential impact was measured through their number of social networks' followers and latest annual revenue. Several statistical analyses were used to determine company and software characteristics that influenced adoption. The results showed dependency between technology penetration and aspects such as the companies' region, lifetime, size, business model and type of technology. Similarly, the data show undiscovered subjects, which may represent new potential for innovation.

126

Improving Early Phases of Building Design by Predicting Pedestrians' Evacuation Times Using Deep Learning Methods

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Building design requires considering multiple requirements and must fulfill diverse regulations.Therefore, model analysis and simulations are fundamental parts of the design process to find the optimalsolution for a given problem. Important decisions are based on a building's assessed final performance in theearly design phases. In particular, the analysis of pedestrian flow dynamics is paramount for public facilitieslike train stations concerning occupants' comfort and evacuation behavior. Currently, it requires multiple steps,from preparing the BIM model to performing pedestrian flow analysis, including semi-automated, often manualwork that demands high computation times. Therefore, to improve the building design efficiency in terms oftime and pedestrian circulation, this paper proposes a framework applying Deep Learning methods. We proposea real-time pedestrian evacuation prediction to replace time-consuming pedestrian dynamics simulations. Moreprecisely, a modular neural network architecture is designed, including a Convolutional Neural Network and aMultilayer Perceptron, that takes floorplan images and building and simulation parameters as input and predictsthe crowd evacuation time for a given building model. As a result, a mean prediction accuracy of 15% could beachieved.

127

Development of augmented BIM models for Built Environment management

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Traditional surveys in the built environment are time-consuming and usually result in enormous amounts of data that are difficult to manage and contain biases. Therefore, BIM modeling of both geometries and related information leads to inconsistent and incomplete models. Alternatively, preliminary BIM models result overly detailed. In both scenarios, the models must be reworked later slowing down the design process. The proposed methodology combines point cloud surveying technique, photogrammetry, and BIM within a game engine platform to define a workflow for an incremental model semantic enrichment that leads to an augmented BIM environment. The case study prototype allows stepwise accurate integration of detailed BIM objects by easing positioning them in the scene in accordance with the overlapped aligned images. This approach provides a way to enrich the BIM model only when required avoiding reworks, reducing working time and costs.

129

Importance of Digitalization and Standardization for Bridge and Tunnel Monitoring and Predictive Maintenance

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This paper reports about preparatory work for future standardization that is carried out through an EU coordi-nation and support action titled IM-SAFE. It focuses on applied digital technologies for monitoring and safe-ty, including predictive maintenance of bridges and tunnels. Amidst the improved affordability of digitaliza-tion technologies and techniques, the biggest challenge in monitoring and maintenance of bridges and tunnels is no longer about collecting data as much as possible, but about obtaining and exploiting meaningful data throughout the lifecycle of the built assets. An effective and efficient data-driven approach is important to al-low both human experts and computers to make accurate diagnostics, predictions, and decisions. Further standardization is seen as an important part to reach that goal.
The work in IM-SAFE related to ICT standardization focuses on the following topics: (1) the general re-quirements and pre-conditions for high-quality and cost-effective acquisition, transmission, storage and pro-cessing of monitoring datasets to ensure the data is fully accessible and machine-interpretable; (2) the rela-tions between the future standards in structural engineering with the open ICT standards for interoperability, especially on Internet of Things (IoT), Building Information Model (BIM), Geographical Information System (GIS), and Semantic Linked Data (LD); (3) a common design of IT platforms to manage monitoring and asset management data of transport infrastructures; (4) the ways to facilitate data analytics technologies, including AI, to be applied for monitoring and asset management of transport infrastructures, and to assess the added value of data-driven approach next to physics-based modelling.
With regard to these topics, this paper reports the outcomes from the expert and stakeholder consultations that recently took place within the IM-SAFE pan-European Community of Practice.

131

A hybrid top-down,bottom-up approach for 3D parsing of Indoor Spaces using dense RGB point cloud

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Nowadays, despite the advanced developments in engineering, automatic large-scale point cloud processing is still one of the challenging topics in many applications. In this regard, segmentation of the indoor point clouds into partitioned spaces is highly demanded in building information modeling (BIM) and robotic society. This paper proposes a novel automatic hybrid top-down, bottom-up approach for the 3D space parsing in the building environment and inferring relations between spaces. The proposed method is based on applying a deep convolutional neural network (CNN) for semantic segmentation of main elements and the use of existing knowledge in the construction of buildings. Unlike the existing methods, the proposed approach does not require pre-knowledge about the space layout.The results of evaluating the proposed method on two datasets with different designs highlight the capability of the proposed approach in 3D space parsing, extracting wall footprints, and particularly finding the topological relation between them.

132

A Lean Strategic FM Service Model Based on the Digital Twin

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The construction industry is committed to improving whole-life performance and minimising waste in building delivery and operations. The construction industry continues to explore Lean and now the digital twin concept from more productive cross-sectors. For the construction industry, digital twins can be seen as a natural maturity of Building Information Modelling (BIM). Digital twins promise to generate value by utilising an estimated 95 percent ofunused data over the lifecycle of constructed assets. The operations and maintenance phase, where facility management (FM) falls, is the most prolonged and costly building lifecycle phase and the most important to optimising built assets' whole life value. This paper applies Design Science Research to propose a Lean strategic FM service model based on the digital twin. The proposed model provides built assets as hubs for Lean strategic service and insight byoptimising facility information management valuevia a digital twin that integrates strategic facility management, Lean visual management, Lean control, Lean problem identification, and continuous improvement toward core business insights leading to productivity and operational efficiency. The findings of the paper motivate novel research on Lean and digital twin-enabled strategic facilities management.

133

Information Extraction and NLP for the interpretation of building permits: an Italian case study

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Assessing project conformity involves extracting information from building regulations and cre-ating rules to verify it. Nowadays, automated systems are already available that assess project conformity but require manual intervention on rule creation, making the process time-consuming and prone to errors. To solve this limitation, this research proposes a new system for extracting information from regulatory codes, which combines the OpenIE6 model with rule-based NLP methods. The articles considered for the search are those containing quantitative values. They were used to train the proposed models to 'learn' the context of words in a sentence or document. From the normative articles, triplets (subject-relation-object) were automatically extrap-olated and used for the creation of conformity rules. A case study is proposed in which the new data mining technology is applied and the conformity analysis is performed. The research is part of a larger project that aims to make the entire compliance process automatic.

134

Digital Twin for AECOO – Framework proposal and Use Cases

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Digital Twin is an ambiguous concept that is often misinterpreted and/or misapplied. It is a con-cept that can bring integrated value across the value chain and therefore needs focus and clarity. The paper presents a framework developed to assist Architects, Engineers, Contractors, Operators and Owners (AECOO)practitioners to determine the purpose and requirements for constructionDigital Twins. Thisdevelopment has its rootson ongoing research performed within the GrowingCircle project scope, following a combination of engagement with practitioners, researchers and expert interviews. The developed framework is utilised to sup-port three real situation use cases.The objective is toevidencethe adjustment andexplain the approachforsolutions to be adopted/implemented.With this practical framework it is meant to support clarity regarding construction Digital Twins as well as provide tools for practitioners to set their requirements determining po-tential suitable solutions.

136

Architectural Education Based on Integrated Design And Its Effects on Professional Life

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Construction industry needs innovations to increase productivity. One of the essential steps taken in this sense is BIM technology in project development. Rather than being a tool for drawing projects, BIM simulates cost, time and quality of construction works. Architecture schools should equip students with BIM knowledge because they are the potential professionals of construction industry. The settlement of BIM in the education programs are carried out in many different approaches of the undergraduate departments. Istanbul Medipol University is a non-governmental university in Turkey that aims to provide interdisciplinary education environment. Architecture, Interior Architecture, Landscape Architecture,and Industrial Design Department students work together on the same project by setting up teams. The aim of the program is to improve working skills with an Integrated Design approach, to educate professionals who are ready to work interdisciplinary in practical life, and to increase the efficiency of the studies from design development to construction with oppor-tunities of BIM. In this paper, the effect of using BIM in the practical life, interdisciplinary working skills and integrated design awareness of the graduates will be investigated through a survey,and it will be concluded whether the education program has reached its goal. For this purpose, a survey for graduate students is prepared for getting feedback of their experiences in their professional life. Within the scope of quality, it is planned to improve the program by combining the survey results and literature research studies.

137

Predicting annual heating energy use using BIM: a simplified method for early design phase

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Building information modeling (BIM) and building energy modeling (BEM) are two key tools to make the transition to net-zero energy buildings (NZEB). However, a recent literature review indicated that the conver-sion from BIM to BEM is currently dysfunctional, due to limitations regarding competencies, processes, and technology. In this article, a case study is presented to show how the information in the BIM model can be used to calculate the annual heating energy use (kWh/m2, year) using the simple degree-day method and ex-tracting building envelope surfaces, heated floor area, and heated volume in the BIM model. The proposed method is for very early design phase (EDP) when architects are starting to determine the general building shape, window sizes, etc. This case study is a residential building called Eskilshem, located in Södermanland, Sweden (latitude 59.4□N, longitude 16.5□E) designed by White arkitekter in 2020. This article presents the workflow and equations embedded in BIM to obtain annual heat energy demand at EDP.

138

Digitalisation initiative of O&G offshore projects contractual procedures

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Oil and Gas Subsea projects contracting status quo is supported by PDF documents interchanging, with relevant data being part of texts, drawings, graphics, and tables. This process dramatically reduces the agility, quality, and traceability requirements and is highly prone to errors. Based on that, the CERTI Foundation, a Centre of Reference in Innovative Technologies and a South American O&G Company deployed a project to digitalise the contractual documentation development. A process mapping of "As is" and "As to be" was conducted following a Business Process Model and Notation (BPMN) approach. Thereby, the project requirements were identified and started the system development. After software solutions mock-ups' and users' feedback, the web-based system development has started. The project aimed to develop a web-based system process-oriented. This digitisation initiative reduces lead time and errors, providing a digital traceability process assuring automated checking and validation.

141

Probabilistic Life Cycle Analysis as a Sustainability-Focused Design Tool for Industrialized Construction

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The Architecture, Engineering, and Construction (AEC) industry is undergoing transformation in two key areas: (1) increased focus on performance-based sustainability metrics to quantify and reduce carbon emissions produced by the built environment and (2) integration of industrialized construction (IC) approaches such as process automation. This research is the first application of probabilistic life cycle analysis (LCA) as a sus-tainability-focused design tool for an early-stage IC concept case study. To produce probabilistic LCA results, a Pedigree Matrix was used to quantify uncertainty in LCA inputs to a Monte Carlo simulation (MCS). The SIPMath Excel® plug-in is used to perform nearly instantaneous, low-cost MCS automatically in Excel®. This is the first use of Stochastic Information Packets (SIPs) as a medium for capturing and using uncertainty information in the LCA of a building. This probabilistic LCA approach improves sustainability metrics in a highly uncertain design space, relative to the initial IC design concept. Research findings show that the proba-bilistic LCA model informed the design team's decision making by providing rapid, targeted, high-level feed-back on decisions such as material choice. Preliminary results indicate a 12% reduction in predicted mean lifecycle carbon dioxide emissions achieved through the IC approach relative to an equivalent conventional construction approach. A rapid, low-cost approach to probabilistic LCA is valuable to industry as a data-driven design tool that informs continuous improvements to design for IC companies. The integration of rig-orous sustainability metrics to quantify and improve the sustainability value proposition of IC versus tradi-tional construction methods has potential to attract and retain customers.

142

On transparency in construction industry materials value chains

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Silos in value chains are functional systems whose reciprocal operation with systems that are, or should be, re-lated is limited. The existence of silos in value chains hinder transparency, opening for shady practices. The purpose of the research presented in this paper is to outline how such silos are erected, maintained and rein-forced within the Norwegian construction industry, with the materials value chains as study object. This study was initiated by literature review concerning supply chain management and traceability within the construc-tion industry. Further, eighteen in-depth interviews were conducted with representatives working at strategic levels from owners/stakeholders, different suppliers, research institutions, contractors and industry organisa-tions. The main results of the investigation can be summarised as follows: 1) the current materials value chains within the Norwegian construction industry are disrupted; 2) the existence of silos is a root cause to the challenges observed; 3) the existence of silos hurts productivity, thereby increasing costs and 4) the ruptures in the value chain hinders transparency and traceability – and thereby paves the way for unethical practices. Current measures for increasing traceability ignore the role of information silos. Addressing practices arising from a lack of transparency and traceability needs by setting such requirements for information management throughout the value chain. Of utmost importance for future research and practice is understanding how to in-clude perspectives of the building in use into the materials value chains. Without concern for the building in use, achieving sustainable construction will prove impossible.

143

Requirements for information management for unforeseen triggering events in the operational phase

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Buildings in the operational phase have great potential for streamlining and simplifying processes related to unforeseen events. The availability and limitation of the necessary information for the roles involved are cru-cial to limit damage and inconvenience. These roles need to define their associated information need in an in-terplay. The standard ISO 19650 series describes recommended, comprehensive, and purpose-driven concepts and principles for business processes to support the management and production of information across the built environment. In an unforeseen critical event in the operational use phase, all involved participants, in-cluding the appointing party, have a short time to do repairs. The client should then be able to start the process using information contained in the asset management system. This study was initiated by several completed interdisciplinary user cases related to how ISO 19650 can be utilized to handle unforeseen events in the opera-tional phase. The main results from the survey can be summarised as follows: 1) The process of clarifying which roles are involved is critical, 2) The "level of information needs" required of actors in the roles in-volved is critical, 3) Clarification of the necessary information is limited to what is needed for the role to be able to decide and thus continue the process, 4) There is identified a need for standardization in developing the information needs and the associated information flow. Based on a description of requirements for a de-fined asset information model (AIM), the surveys propose a simplified process description for requirements for information management related to unforeseen events. The study shows the importance of clearly specify-ing and delivering the required information but is still sufficient to solve the various roles tasks. At the same time, the need to develop "best practice" is revealed.

144

High order second-level space boundary topology calculation for building energy performance simulation modelling

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A second-level space boundary surface is the surface through which thermal energy flows between internal building spaces and the building environment. To set up whole building energy simulation models, knowledge of these boundaries is required. The geometric challenges associated with identifying these second-level space boundaries are compounded when considering overlapping multi-layer building constructions --- a particular case but one often encountered in practice. In the present work, we introduce the concept of high-order (greater than two) space boundary surfaces and a geometric algorithm to identify such surfaces from Building Information Models. The proposed algorithm extends our earlier work on first-order second-level space boundary calculation. We use as input building information models from real buildings, to demonstrate the efficacy of the proposed algorithm. In particular, we consider a facade retrofitting application scenario, where external and internal multi-layer elements are added. The algorithm identified correctly second and third-order second-level space boundaries, related to these additional elements.

146

Optimising energy and daylight simulation workflow through openBIM and the web

Franz Forsberg

Current daylight and energy performance evaluation practices vary greatly in the industry due to a lack of ro-bust software packages allowing for consistent interoperability. Those deficient workflow result in high evalu-ation costs due to the large number of hours used for simulation preparation, and in a compliance-chasing atti-tude in which assessing for qualities beyond the minimum regulation is a luxury often left aside. As an attempt to create awareness around the benefits of structured hierarchy models for the building simulation community, this paper describes methods solving identified silos based on openBIM, web technologies, and custom-made algorithms, resulting in smart and streamlined evaluation workflow greatly reducing assessing time and costs. The resulting platform-neutral web application is more than a proof-of-concept, it has as ambition to lift our industry inefficient practices and inspire others in this critical time of societal green transition.

147

Barriers to digital traceability in the materials value chains for assets

Knud Mohn, Dr., research scientist Jardar Lohne

This paper identifies barriers to (digital) traceability in the construction industry today, based on lliterature a review, eighteen in-depth interviews representatives working at strategic levels from owners / main stakeholders, various suppliers, research institutions, contractors and industry organizations, and four in-depth interviews were conducted with other industries, which have gone further with the digitization processes than the construction industry, to see which successful methods they have used to succeed with traceability for their purposes
This paper identifies barriers to (digital) traceability in the construction industry today, based on lliterature a review, eighteen in-depth interviews representatives working at strategic levels from owners / main stakehold-ers, various suppliers, research institutions, contractors and industry organizations, and four in-depth inter-views were conducted with other industries, which have gone further with the digitization processes than the construction industry, to see which successful methods they have used to succeed with traceability for their purposes and which ICT technologies have been used. A main challenge identified within the material value chains of construction projects is that most trading processes are analogous and determined by the contracted contractors and their subcontractors. Increased traceability requires increased client involvement. Without knowing which products are used in the buildings, it will prove impossible to understand how the buildings should report according to environment and other. This requires the development of digital processes.

149

Designing the business model for the end-of-life phase

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Business models for reuse and recycle processes in the context of circular economy are becoming essential for a new realization of the end-of-life phase. On the other hand, existing business models for design and con-struction need to be reconfigured for the inclusion of reusable and recyclable building components and mate-rials. This implies a necessary change in the Architecture Engineering Construction industry. Examining exist-ing business models for the built environment from literature and practice in AEC, shows that there are almost none so far for the end-of-life, or very few with a limited stakeholder focus on certain parts of activities in the buildings´ LC. In this paper, we aim at answering the question: How can business models for the end-of-life (BiMEL) phase be designed? Grounded in the Design Science approach, we present a framework, where the business model is an artifact, as artifacts are built to address unsolved problems.

150

Information extraction from project-related text documents using natural language processing and machine learning methods

Meiling Shi

The exploitation of using text documents from precedent projects for decision-making in the construction in-dustry is still at a low level. One reason is that the in unstructured natural language formulated information cannot be processed directly by computer programs and the search is conducted by keywords-match, which is inefficient and imprecise. To make the information of unstructured text document accessible in digital pro-cesses without introducing additional manual work, we propose using natural language processing and unsu-pervised learning methods to automatedly extract information from unstructured textual documents. This pa-per describes an NLP-based pipeline that includes methods for data acquisition and preprocessing, different transformer-based embedding methods, and subsequent downstream tasks. Our proof-of-concept is trained on documents from different waterways construction projects in the German language. Because of the unsuper-vised learning and available language models, this pipeline can be generalized to other languages and construc-tion types.

152

Tower crane layout planning through Generative Adversarial Network

Rongyan Li, Junglin Chi, Zhenyu Peng, Junyu Chen

Tower cranes are globally utilized in construction projects to transport components vertically and horizontal-ly, which governs the construction schedule and requires proper locations. However, in practice, the layout of the tower crane is mainly decided by the experience of construction contractors or managers, lacking quality assurance. Generative adversarial network (GAN) is an emerging deep learning technology to gener-ate synthetic images with predictive nature, applied in many research areas, especially in automatic design. Given that, this paper proposed a TC-GAN to identify an appropriate tower crane layout. Information on construction projects was gathered and calculated to obtain a high-quality training dataset considering effi-ciency and safety. Then, a framework derived from cGAN was applied for the TC-GAN generator and dis-criminator, training on the massive dataset. The learning rate selection was conducted based on evaluating the quality and rationality of the generated image, which validated the TC-GAN performance in tower crane layout planning.

153

Correlation and comparison between Digital Twin and Cyber Physical Systems

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Advanced technologies like Internet of things (IoTs), Artificial Intelligence (AI), blockchain, Augmented Reality (AR), analytics etc., have significantly accelerated the development of smart manufacturing. Manufacturers are promptly adopting cyber–physical integration as a prerequisite for smart production. Cyber–physical systems (CPS) and digital twins (DTs) are two popular technologies that are utilized as a preferred mean of integration. Regardless of their differences, both technologies have several commonalities that cause them to be misunderstood. Therefore, it is important to distinguish these two technologies in order to consolidate future research. Through a systematic literature review, this paper compares and contrasts CPS and DTs from several angles in order to highlight the differences and correlations between them.

156

A multi-representation method of building rules for automatic code compliance checking

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In the Architecture, Engineering and Construction (AEC) industry, design review is an important step that often leads to project delay, as the typical manual compliance checking process is error-prone and time-consuming. As an approach to accelerate this process and achieve a better quality of design, automatic compliance checking (ACC) has been researched for several decades. Rule interpretation and representation is a bottleneck of ACC. It focuses on the interpretation of regulations and the represention of them in a suitable computer-readable form. Despite extensive research efforts, a rule representation method that is suitable to represent all types of rules has yet to be proposed. To address this issue, this research proposed a multi-representation method that provides a “mix and match” for different representations and different types of rules, thereby representing all types of rules with suitable representations. This research is valuable to both academia and industry as it enables the representation of rules with less knowledge loss and more accuracy.

157

Training on digitised building regulations for automated rule extraction

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We investigate automated rule extraction from building regulations using a neural semantic parser. This task is regarded as a main requirement to enable automated compliance checking in the built environment. The performance of deep learning models is strongly dependent on the quantity and quality of the training data and the task complexity, which is particularly relevant for domain-specific tasks with limited data and domain-specific terminology. The neural semantic parser is trained using a corpus of LegalRuleML rules, which were manually en-coded in previous research. We identify the primary error sources for automated parsing, investigate the importance of data quality and consistency and rework the entire corpus accordingly. Extensive experiments indicate the impact of different inconsistencies. Value conditioning was evaluated to limit the effect of varying granularity, complex expressions, and tacit knowledge. Finally, we draw conclusions about the encoding guidelines and processes from a natural language processing perspective.

158

Practical experiences with 5D Building Information Modeling – a systematic literature review

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Cost planning and control are basic tasks in the projects of the Architecture, Engineering, and Construction (AEC) industry. Implementation of Building Information Modeling (BIM) in costing practices, so called 5D BIM, is supposed to overcome several challenges in traditional cost estimation. The aim of this study is to investigate how theoretical concepts of 5D BIM are transferred into real AEC projects and how the practical experiences with 5D BIM are presented in scientific production. For this, a systematic mapping study was performed, covering only the publications in a scientific paper format published between 2000 and 2022. Af-ter establishing inclusion and exclusion criteria, a total of 166 articles were mapped, classified into elaborated categories, and analyzed by a set of indicators (e.g., time evolution, research approach and methodology, pub-lication vehicles, etc.). The results are discussed in the context of technology, processes, people, and stand-ards, using a multi-perspective view of innovation. Our study is a descriptive study intended to stimulate fur-ther research in the field of information management and technology implementation.

159

Semantic Material Bank: A web-based linked data approach for building decommissioning and material reuse

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In light of the global awareness regarding unsustainable resource extraction, material consumption and waste generation within the Architecture, Engineering, Construction (AEC) domain, circular economy strategies are encouraged to be used in all aspects of construction projects. Circular construction relies on the exchange of information between project actors that are a lifecycle apart: an element used in one building can be deconstructed, assessed, re-certified and re-used in another one. For this cycle to complete, a plenitude of information needs to be exchanged between stakeholders. Yet, a thwarting challenge in the AEC domain is the lack of information interoperability. To address this issue, linked data and semantic web technologies are among the promising solutions. As the main contribution, this study proposes two semantic web ontologies in order to provide an open and future-proof circular construction information exchange solution. The Deconstruction & Reuse Ontology (DOR) semantically expresses the decommissioning lifecycle stage of buildings, material bank and the subsequent material and component reuse. This ontology targets the material loop gap between decommissioning and new design lifecycles while complementing the existing circular construction ontologies. The accompanying ontology describes the lifecycle impacts of construction products based on ISO 21930. The Ontology for Environmental Product Declaration (OEPD) could help to semantically tag manufacturer products in future, which makes lifecycle assessment information easily accessible for humans and readable for machines. The proposed ontologies are validated through the SPARQL Protocol and RDF Query Language (SPARQL) queries. Finally, both ontologies are employed in a case-study to demonstrate the Semantic Material Bank (SMB) proof-of-concept. SMB is a work-in-progress digital urban mining solution enabling stakeholders to evaluate the availability and status of reusable or recyclable elements at the urban level. Through this semantic web-based tool, designers and decision-makers can find suitable reusable materials to re-employ in their new designs.

160

HBIM application in historic town: A scoping literature review of published case studies

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The use of BIM as data management platform for the AEC sectors has been observed primarily in the design-ing and building phases rather than in post-construction applications such as facilities management and con-servation. As the concept of BIM reached maturity, there has been a growing interest in applying the technol-ogy to heritage buildings and towns. This paper examines the phenomenon by considering how the HBIM ap-plication in managing historic towns might be described and what type of information will give further in-sights. This study is using a scoping literature review. Finding showed that the HBIM is involved in every critical step of the HUL approach by exploiting the technology to better mapping the heritage resources, inter-preting heritage technical knowledge, digital assessment of vulnerabilities, enhancing efficiency, and prioritiz-ing action to be made. The digitization is costly and time spending, but the HBIM output demonstrate a supe-rior potential to manage historic towns.

161

Data sovereignty within the construction process

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Creating and sharing more data within the value chain during the whole life cycle of a building is regarded as one of the key elements towards the digitalization of the construction sector. Although many stakeholders are willing to share data, they fear the potential misuse and loss of control over their data. The concepts behind data sovereignty and the legal value remains vague in political as well as scientific discussions. The paper identifies the dimensions of data sovereignty and links them to the legal concepts of data governance including technical and organizational standards in construction law. Based on these findings a definition of data sovereignty is proposed. Thereinafter, stakeholder roles and interests are examined and legally categorized by transferring concepts of data and IP law. Finally, legal and organizational measures are derived for establishing and documenting data sovereignty as part of the construction process.

162

A model to extend BIM interoperability for cast in-situ concrete monitoring

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Cast in-situ concrete construction is a traditional construction technique, involving a demanding information flow and high requirements for documentation of material properties. Such an information-intensive process often lacks of efficient and systematic support from digital tools. There is a great potential to further improve the quality and management of cast in-situ concreting by extended use of digital data. This study explored the existing cast in-situ process of a Norwegian construction company and present a production overview were the monitoring of cast in-situ data is digitally supported. Thus, expanding the interoperability of Building In-formation Modelling (BIM) and embedded concrete sensors for better management support. The findings suggest that sensors data (i.e., development of temperature, strength, and humidity), can be easily connected to project specific applications and models. However, action is needed to establish interoperability on all levels and support real-time communication. The short-term impact improves production control. The long-term im-pact is improved documentation and circularity throughout the service life of the built asset.

163

VDC framework proposal for curtain wall construction process optimization

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A building is made up of structural and non-structural elements. Among these are the curtain wall systems. The curtain walls are glazed elements that can cover the building façade entirely and provide thermal and en-closure properties. Despite its use worldwide, some challenges have been identified in the construction process related to transportation, communication between the stakeholders, and the installation itself. A VDC framework is proposed to overcome these challenges, including an implementation workflow and an interrelationships map between the VDC components. This study specialized on a multiuse 12,000 m2 building under construction in Lima, Peru, resulting in an optimized proposal for curtain wall construction, compared to the traditional construction flow.

164

Construction process time optimization of a reinforced concrete reaction slab, implementing the VDC methodology

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The Architecture, Engineering, and Construction (AEC) industry has shown low productivity levels, mainly due to the fragmentation between the agents involved. Given this, the industry is modernizing and implementing collaborative methodologies to improve the development of projects. One of them is the VDC (Virtual Design and Construction) methodology. VDC allows us to improve design, construction, operation, and maintenance management, changing paradigms within traditional processes. This research shows how implementing VDC can help to optimize the construction process time of a reinforced concrete reaction slab in a civil engineering laboratory. As a main result, an optimized process was developed, generating a 44-day reduction in the construction time of the reaction slab.

166

Evaluating existing digital platforms enabling the reuse of reclaimed building materials and components for circularity

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In Europe, several examples for digital marketplaces for reuse of reclaimed building materials and components could enable more circularity in the architecture, engineering and construction (AEC) sector. Not many re-search and perspectives on digital platforms for reuse offer a compass for AEC to evaluate existing platforms. In this explorative and reflective paper, we identified and evaluated around 20 markets in Europe and one in North America, which are representative for its local or regional market. We explored them through a set of pre-defined functions (e.g., basic functions, service for selling), and the access to information. Many markets are segmented, small-scale, prototype platforms and initiatives not yet replicated or scaled up for wider use. We argue to take a multiple user group perspective, as different stakeholders are needed to collaborate and exchange materials and information; this requires seeing suppliers of materials and information as possible user groups. We propose a set of questions and guidelines for evaluation, according to match requirements of mul-tiple user groups and functions of the platform, the capacity of sharing risks, costs, benefits and profit, circu-larity targets and a regional perspective.

167

Construction product identification and localization using RFID tags and GS1 data synchronization system

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The topic of this paper has been motivated by interest of new technologies in the area of civil engineering. New digital ways of design, oversight of manufacturing, construction and ways of upkeep and control of already completed structures are observed in fast developing industry branches. These methods which are gaining popularity in Poland are often already a standard in other countries where building information modeling BIM is present in engineering, facility management and state administration practice.

168

Using metrics to compare VDC elements in practice by general contractors in Norway

Tulika Majumdar

ABSTRACT: Despite increasing interest in VDC (Virtual Design and Construction), it has been difficult to compare VDC practices across AEC (Architecture, Engineering and Construction) project teams. VDC theory states that all three of its key elements, i.e., BIM (Building Information Modeling), ICE (Integrated Concurrent Engineering) and PPM (Pro-ject Production Management), should be used together in an integrated way. Content analysis was used to find evi-dence of the use of BIM, ICE and PPM, in production metrics reported by 57 AEC professionals representing general contractors in Norway. ICE production metrics were reported by 83% of the professionals, followed by PPM (70%) and BIM (34%). A survey with a list of production metrics was provided to another group of 50 professionals, also representing general contractors in Norway. Survey results showed an increase in the reporting of production met-rics for all the three elements, most dramatically for BIM (from 34% to 90%). This study illustrates that comparing production metrics fosters understanding of VDC elements in practice. It also opens pathways to future research on a) a joint understanding of VDC elements, in particular BIM, and b) a systematic classification of production metrics for a reliable understanding and comparison of VDC elements used in practice.