BIM for geotechnical engineering

Author: Prof. Dr.-Ing. habil. Heinz Konietzky
(TU Bergakademie Freiberg, Geotechnical Institute)

Editor: Prof. Dr.-Ing. habil. Heinz Konietzky Layout: Gunther Lüttschwager
TU Bergakademie Freiberg, Institut für Geotechnik, Gustav-Zeuner-Straße 1, 09599 Freiberg • sekr_fm@ifgt.tu-freiberg.de

1 Introduction

Within the last few years BIM (**B**uilding **I**nformation **M**odelling) has taken over a central role in the AECOO (**A**rchitecture, **E**ngineering, **C**onstruction, **O**wner, **O**perator) industry and is often a pre-requisite to get contracts and to perform corresponding constructions (Bradley et al. 2016). Today adaption rate of BIM in AECOO is already beyond 50% worldwide and still increasing.

BIM in geotechnics can be considered as a consequent further development of classical CAD (**C**omputer **A**ided **D**esign) and GIS (**G**eographical **I**nformation **S**ystems) by incorporation of several additional elements and considering a construction from the early stage of planning over the whole lifetime including demolishing. If we restrict BIM to geotechnical engineering we have to focus on the following areas:

- Transportation infrastructure - roads, railways, bridges, tunnels, habours and mass transit hubs
- Energy infrastructure – power generation plants (nuclear, wind, tidal etc.), oil & gas (storage and distribution terminals, refineries, wells etc.)
- Surface and underground mining
- Utility infrastructure – networks and pipelines for the delivery and removal of electricity, gas, water & sewage
- Recreational facilities infrastructure – parks, stadiums etc.
- Environmental infrastructure – Structures for managing flood and coastal defence such as dams, levees, weirs or embankments
- Measures (constructions) to manage natural hazards and mass flow in mountain regions (avalanches, rockfall, slope instabilities etc.)
- Maintenance of stone monuments or other historical stone-based constructions like bridges, walls, castles etc.

Fig. 1.1 documents that BIM is becoming a world-wide standard for at least bigger projects, for instance (see also Fig. 1.1.):

- In Germany and Great Britain BIM is obligatory as of 2020 for all public constructions
- In Spain and Russia BIM is obligatory as of 2019 for all public constructions
- In China BIM is defined as standard for all constructions since 2020
- In South Korea BIM is obligatory since 2016 for constructions with volume bigger than 50 Mio. US-Dollar
- In Wisconsin (USA) BIM is obligatory since 2010 for public constructions with volume bigger than 5 Mio. US-Dollar

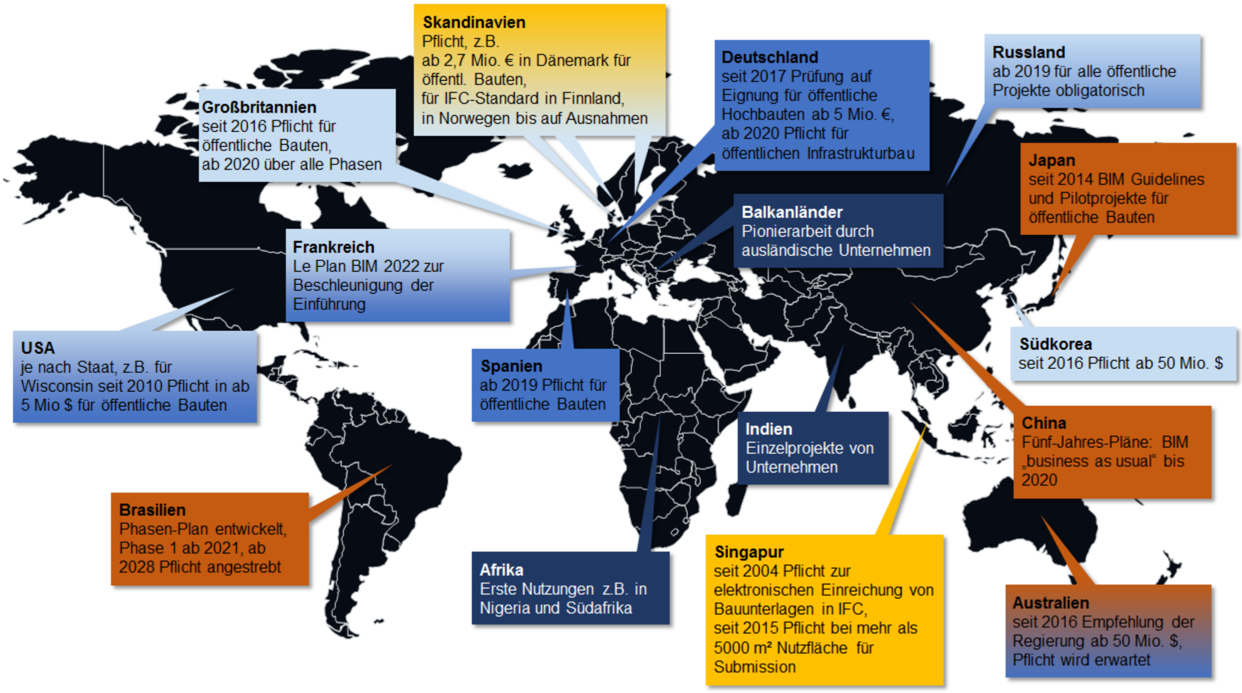


Fig. 1.1: Status of worldwide application of BIM (DVW, 2019)

2 BIM concept

Bradley et al. (2016) give the following definition of BIM:

> *"BIM is defined as the art of information management & collection by CPIC (Construction Project Information Committee); a process that runs through the entire asset lifecycle and a digital representation of physical & functional elements of an asset used for decision making. What is common from these definitions is that the BIM concept is made up of four key elements: collaboration, representation, process & lifecycle which all interact with each other to create an innovative and efficient project environment [see Fig. 2.1]. BIM as a process involves the generation and management of data and information associated with an AECOO industry project over its entire lifecycle from brief to decommissioning"*

Nowadays BIM of highest level considers the project in 9 dimensions:

- Three dimensions in space
- Time
- Costs
- Actual, built state of the project
- Building / structure in use
- Predicted / planned renovations or retrofits
- Demolition at the end of the lifecycle

BIM activities are illustrated by Succar (2009) as shown in Fig. 2.2. Three fields of activity are specified:

- Policy field (responsible for regulations, standards, education, research etc.)
- Process field (ordering of work activities performed by managers, owners, engineers, suppliers etc.)
- Technology field (soft- and hardware)

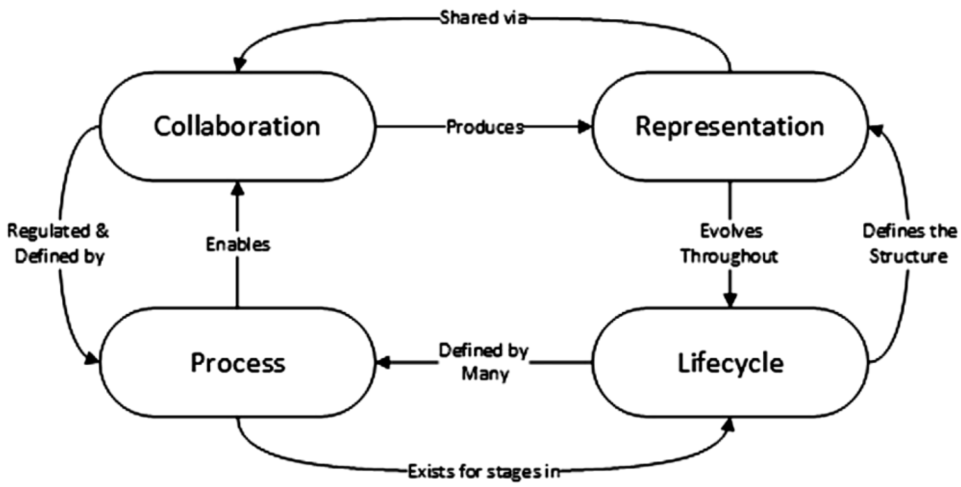


Fig. 2.1: Key elements of BIM and their interaction (Bradley et al., 2016)

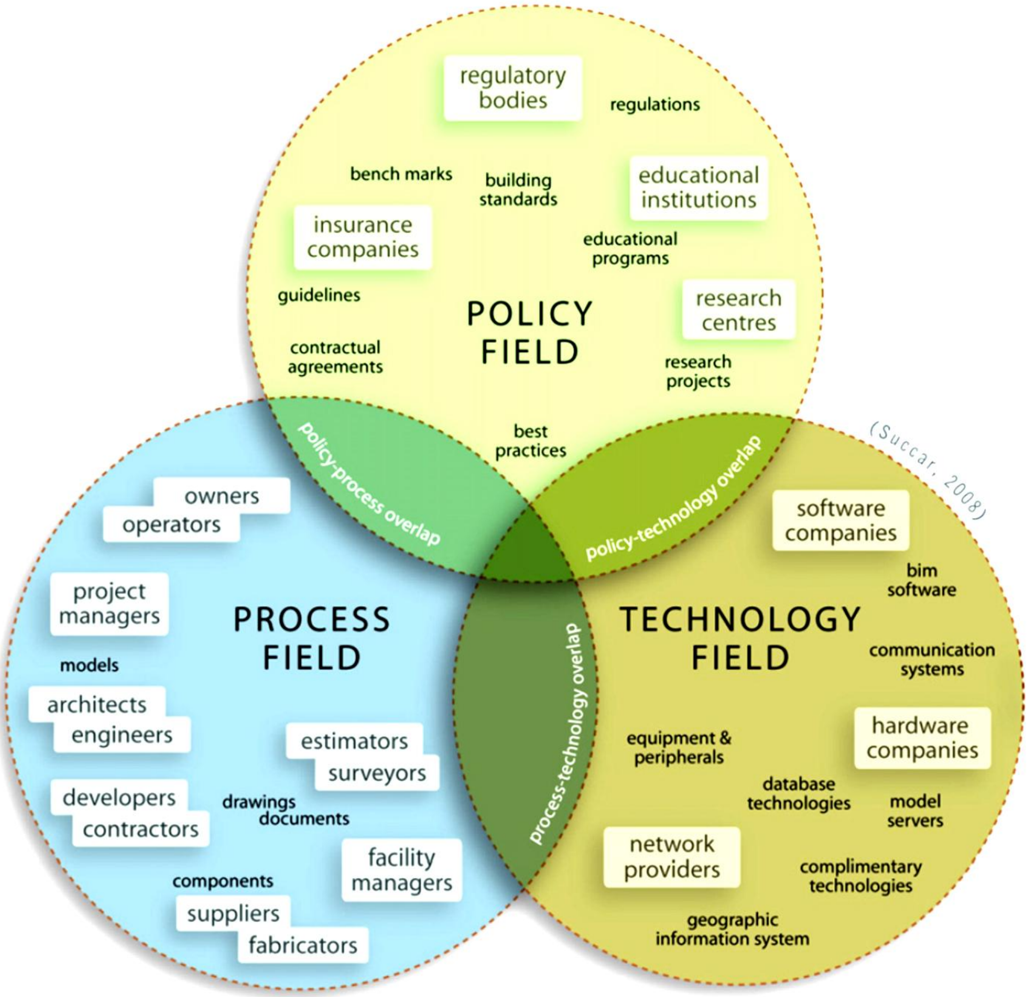


Fig. 2.2: Fields of BIM activities (Succar, 2009)

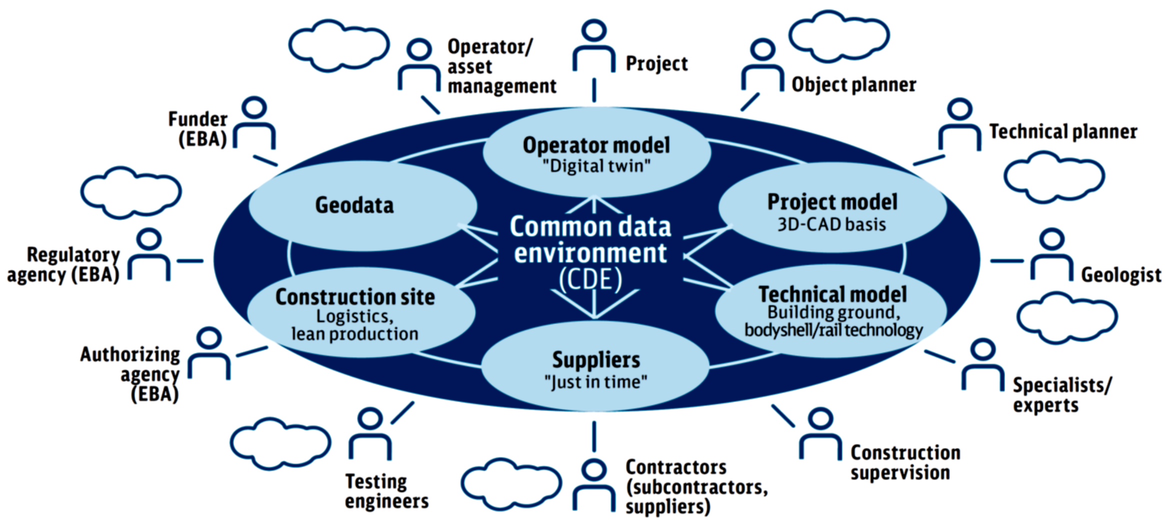


Fig. 2.3: Shared common data environment with access provided for all project members (DB AG, 2019)

Fig. 2.3 illustrates interaction and access of BIM partners in relation to the common data environment (CDE). CDE is a key element of BIM and guarantees that all partners have same information and data, respectively. Two key persons are necessary to run BIM projects:

- *BIM manager*: responsible for the structure of the project, the software and data formats incl. exchange procedures and the maintenance of the models
- *BIM coordinator*: responsible for coordination of the BIM planning with all the project partners (e.g. coordination of sub-models, consistency check etc.)

BIM can be characterised by so-called BIM maturity or levels (Fig. 2.4), which characterise the development level (only Level 3 fulfills BIM requirements in a complete manner):

- *Level 0:* 2D-CAD models, data exchange via paper maps and digital plots
- *Level 1:* Mix of 2D- and 3D-CAD Models, data exchange via common data environment
- *Level 2:* 3D-CAD-Models, partially already shared models, collaboration via united formats
- *Level 3*: management and coordination of all project data via one model, all members have access to the same status

A complete working scheme (BIM cycle) with all its components is shown in Fig. 2.5.

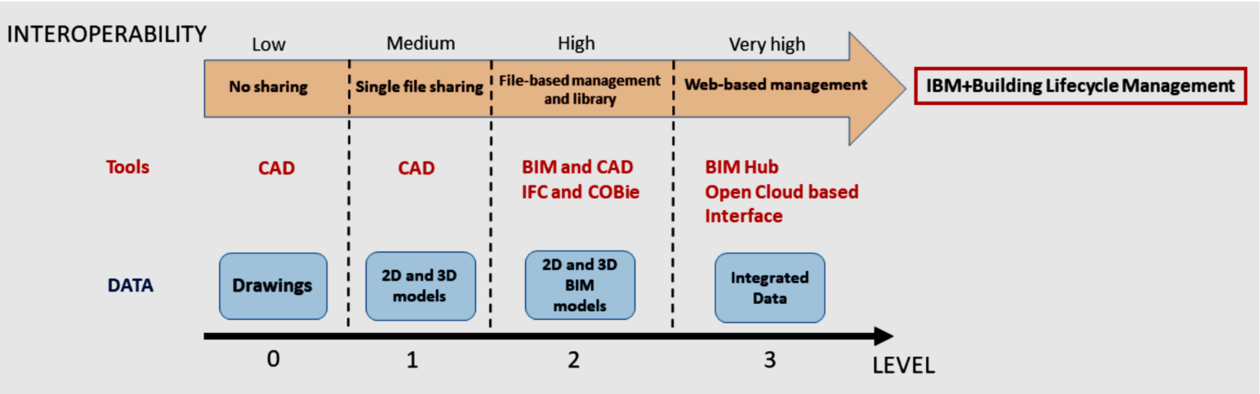


Fig. 2.4: Overview about BIM levels (Mery, 2019)

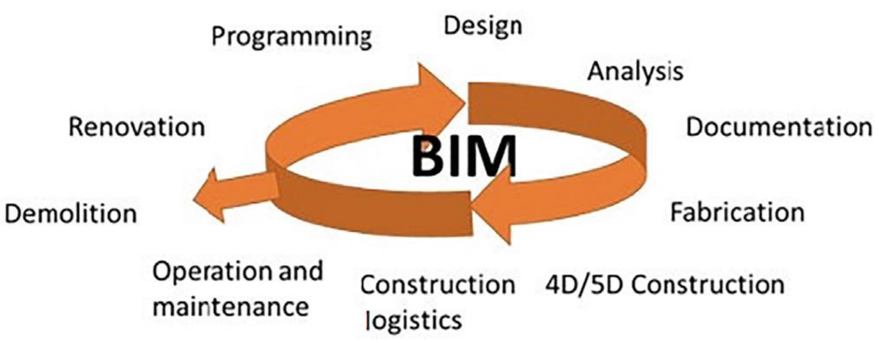


Fig. 2.5: BIM working scheme (Chapman et al., 2020)

BIM software uses the IFC (**I**ndustry **F**oundation **C**lasses) format. IFCs have been developed by buildingSMART (bSI) as an open standard for sharing BIM data with different software applications. IFC is registered under ISO-16739. Since 2014 IFC-4 is used. The IFC format is based on STEP (**St**andard **E**xchange of **P**roduct Model Data), which is part of ISO-10303. STEP is an open format and independent of used software. STEP describes the components of an object, e.g. a building, physically and functionally (see Fig. 2.6). STEP defines geometric values, properties, relations to other objects and life cycles. Besides STEP, the format XML (**Ex**tensible **M**arkup **L**anguage) is very popular and often used for BIM projects. It is important to update any kind of information in a permanent manner (see Fig. 2.6, left). In general BIM software should be able to handle quite different data and file formats, like illustrated in Fig. 2.7, right. Fig. 2.8 shows the timeline of the IFC development.

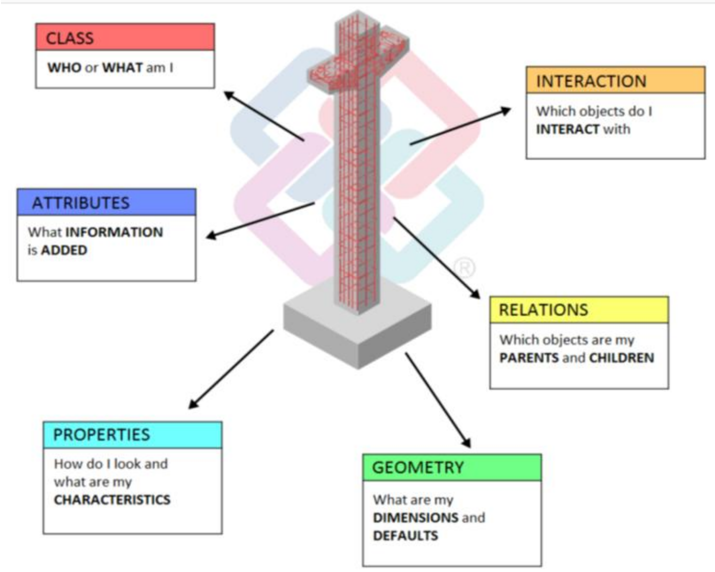


Fig. 2.6: Illustration of an object with its components (Allplan, 2016)

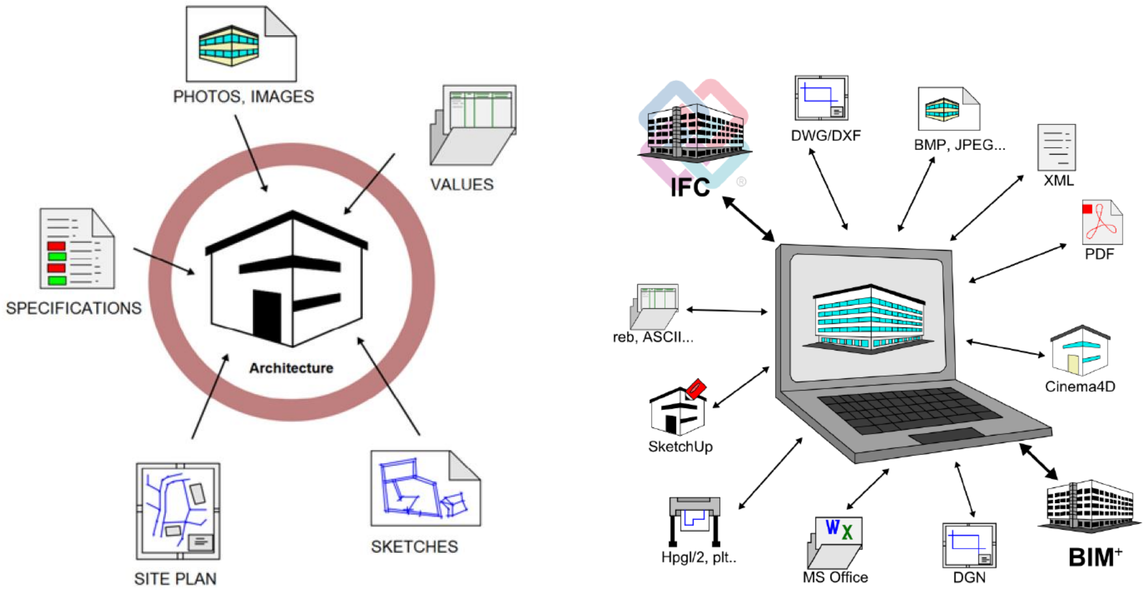


Fig. 2.7: Exemplary illustration of object related inputs like data, information, maps etc. (left) based on different formats (right) (Allplan, 2016)

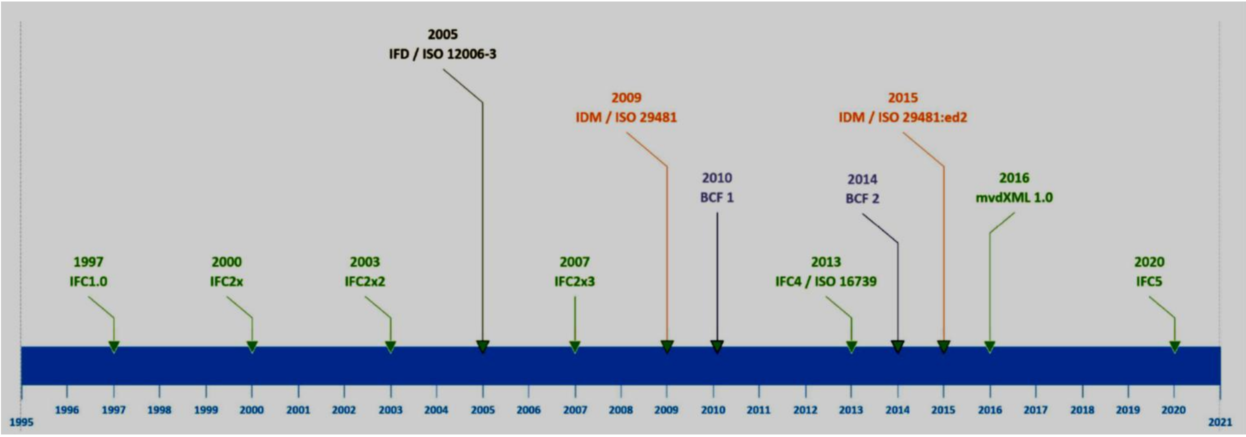


Fig. 2.8: Timeline of IFC development (buildingSMART International)

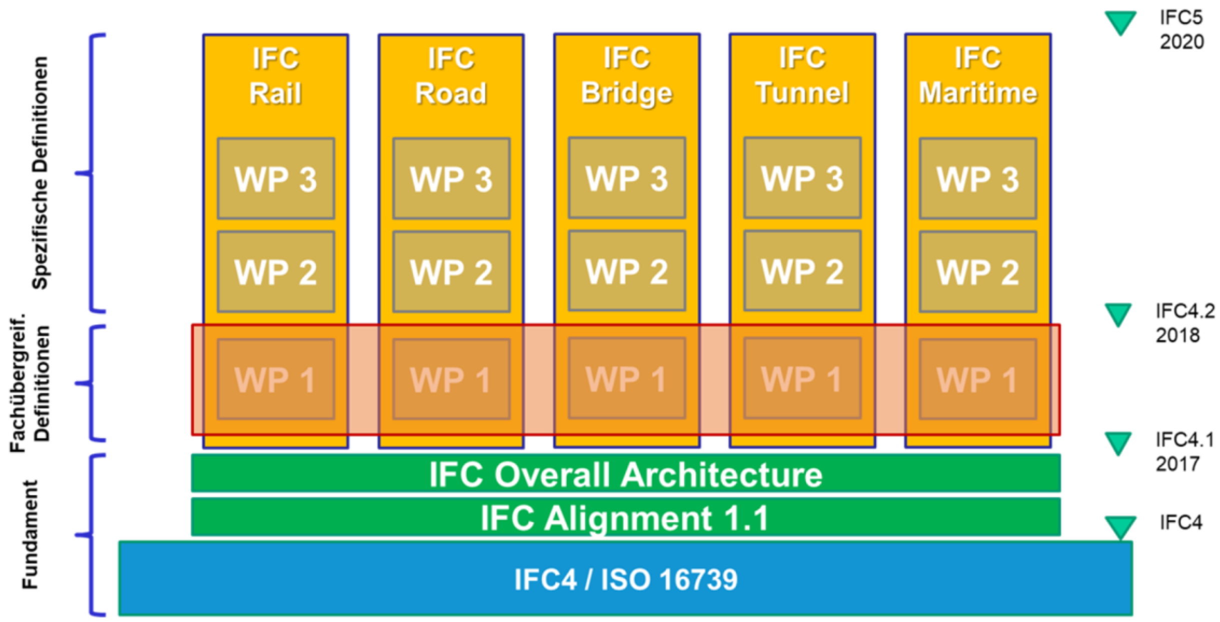


Fig. 2.9: Extension of IFC to cover also geotechnical constructions (DVW, 2019)

As shown in Fig. 2.9 the IFC were extended to cover also common civil engineering and underground constructions, like railways, roads, bridges, tunnels and maritime constructions.

The following simple example illustrates the syntax of an IFC-4 XML scripting to create a cube by extrusion of a rectangle in the x-y-plane with extension 2000 x 800 mm and vertex position of 0,0,0 into the third direction (z-direction), so that the height of the brick becomes 800 mm:

```
<IfcExtrudedAreaSolidid="i1922" Depth="800.">
    <SweptAreaxsi:type="IfcRectangleProfileDef" id="i1925" ProfileType="area"
    ProfileName ´="1m x 1m rectangle" Xdim="2000." Ydim="800."/>
        <Position xsi:type="IfcAxis2Placement3D" id="i1928">
            <Location id="i1959" Coordinates="0. 0. 0."/>
        </Position>
    <ExtrudedDirectionid="i1931" DirectionRatios="0. 0. 1."/>
</IfcExtrudedAreaSolid>
```

The scipt uses several IFC‘s like: IfcExtrudedAreaSolidid, IfcRectangleProfileDef, IfcAxis2Placement3D or IfcExtrudedAreaSolid. A more complex solid is produced by the following IFC-4 XML script:

```
<IfcCsgSolid>
    <TreeRootExpression>
        <IfcBooleanResult Operator="difference">
            <FirstOperand>
                <IfcBlock XLength="2000" YLength="800" ZLength="800">
                    <Position>
                        <Location xsi:nil="true" href="i2" />
                    </Position>
                </IfcBlock>
            </FirstOperand>
            <SecondOperand>
                <IfcExtrudedAreaSolid Depth="700">
                    <SweptArea xsi:type="IfcRoundedRectangleProfileDef" Profile-
                    Type="area" ProfileName="VoidProfile"
                    XDim="1800" YDim="600" RoundingRadius="200" />
                        <Position>
                            <Location Coordinates="1000 400 100" />
                        </Position>
                    <ExtrudedDirection DirectionRatios="0 0 1" />
                </IfcExtrudedAreaSolid>
            </SecondOperand>
        </IfcBooleanResult>
    </TreeRootExpression>
</IfcCsgSolid>
```

This script produces a rounded concave brick-like polygon (bathtube). Outer dimensions are the same as for the brick given in the frist script. The inner volume is 1800 x 600 x 700 mm. The rounding radius is 200 mm. The scipt uses several IFCs like: IfcCsgSolid, IfcBooleanResult, IfcBlock, IfcExtrudedAreaSolid, IfcRoundedRectangleProfileDef or IfcExtrudedAreaSolid.

The level of detail (see also Fig. 2.10), also called model granularity, can be subdivided into different categories (DAUB 2019):

- Level of Geometry (LoG): geometry level of construction elements
- Level of Information (LoI): attributes for construction elements
- Level of Detail (LoD): = combination of LoG and LoI
- Level of Development (LOD): degree of maturity according to project phase

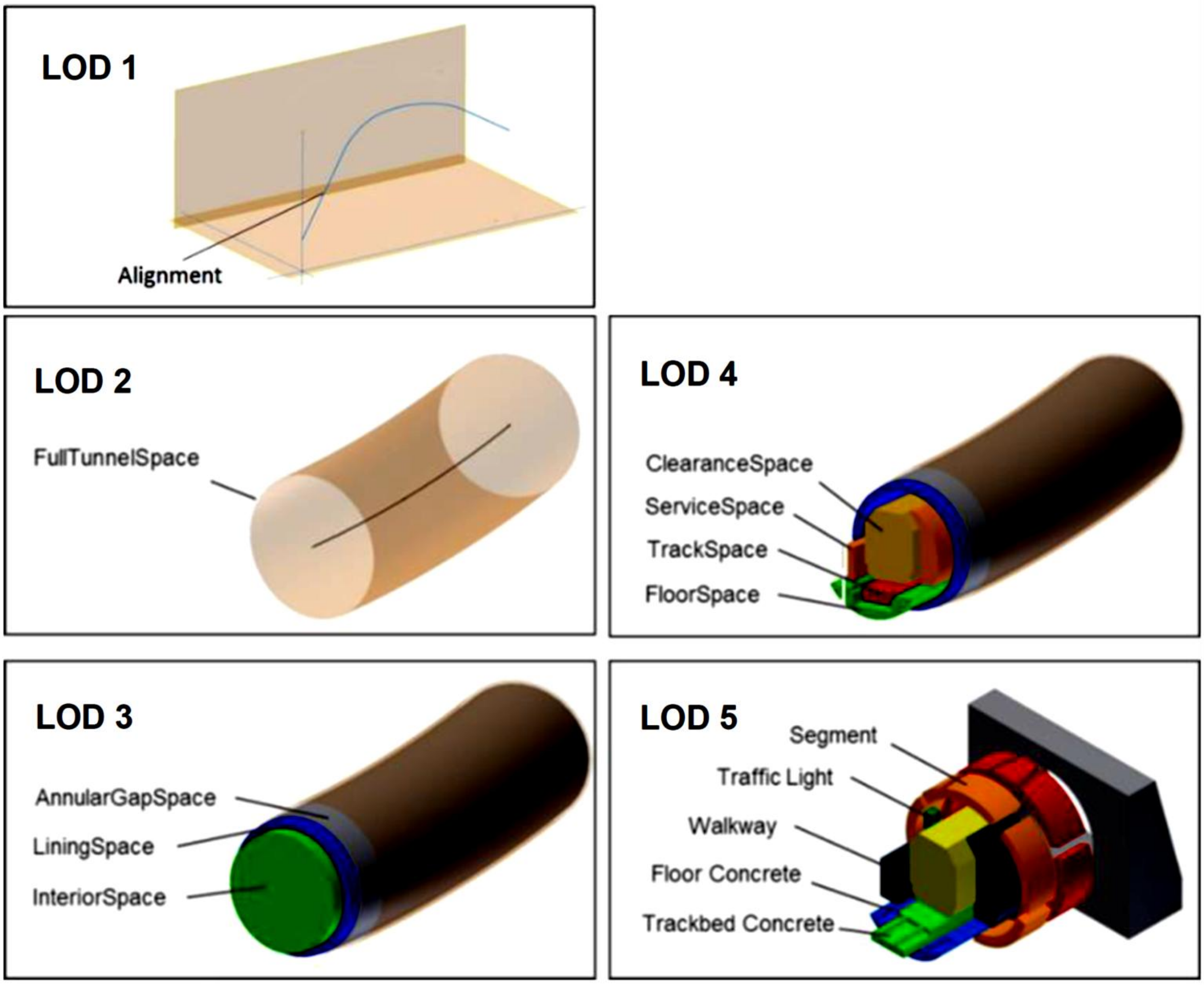


Fig. 2.10: Illustration of LoD for a tunnel excavated with tunnel boring machine (DVW, 2019)

BIM considers several dimensions (see also Fig. 2.11):

- 3 dimensions in space
- 1 dimension in time
- 1 dimension in costs
- 1 dimension in facility management
- 1 dimension in sustainability
- 1 dimension for safety

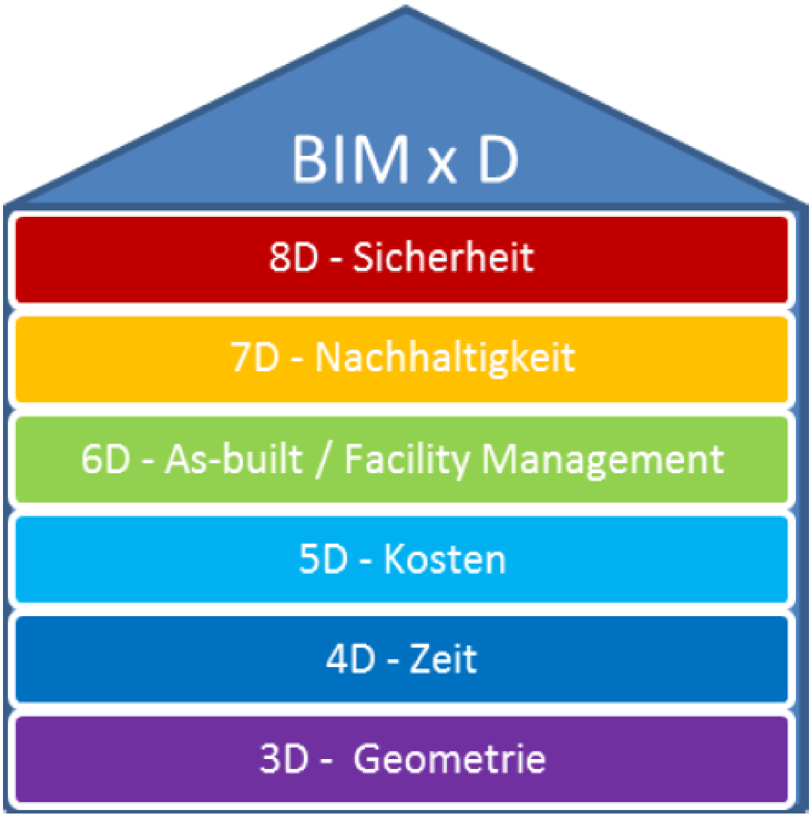


Fig. 2.11: Multi-dimensionality of BIM (DVW, 2019)

There are already several publications which deal explicitly with geotechnical aspects in BIM, for instance Tawelin & Mickovski (2016), Morin et al. (2014), Obergriesser & Borrmann (2012), Möller & Mahutka (2018), Morin (2018) or DAUB (2019). Reflecting the work of DAUB (2019) most important BIM project phases are listed exemplary for underground constructions like tunnels:

1. Pre-planning
    a. *Data aquisition*
    b. *3D geotechnical model*
2. Planning
    a. *Variant analysis*
    b. *Visualisation for public relations work*
    c. *Dimensioning / safety demonstrations*
    d. *Coordination of technical disciplines / trades*
    e. *Progress monitoring of planning*
    f. *Preparation of design plans / authorization plans*
    g. *Occupational safety / environmental prorection*
    h. *Approval of planning documents*
    i. *Cost estimations and calculations*
3. Preparation of execution
    a. *Service specifications*
    b. *Tender specifications*
    c. *Tendering procedure*
4. Execution
    a. *Scheduling of excecution*
    b. *Logistics planning*
    c. *Preparation of technical execution planning*
    d. *Checking the progress of construction*
    e. *Modification management*
    f. *Invoicing of construction works*
    g. *Management of construction shortcomings*
    h. *Documentation of structures*
5. Operation incl. Monitoring
6. Maintanance / Repair / Extensions
7. Demolition (may be not in case of tunnels, but other projects)

3 Digital Twins

The heat of a geotechnical BIM project is the digital twin. The digital twin mimics structure, context, and behaviour of a natural, engineered, or social system which is dynamically updated with data from its physical counterpart and has a predictive capability to inform decisions for realising value.

The digital twin experience increasing maturity during the construction (Babanagar et al. 2025):

- Descriptive twin
- Reflective twin
- Predictive twin
- Prescriptive twin

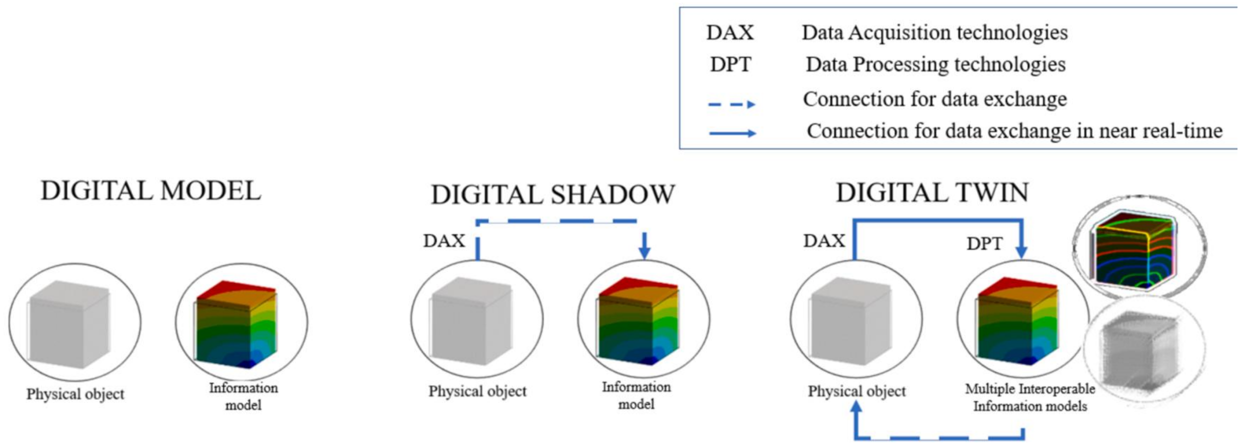
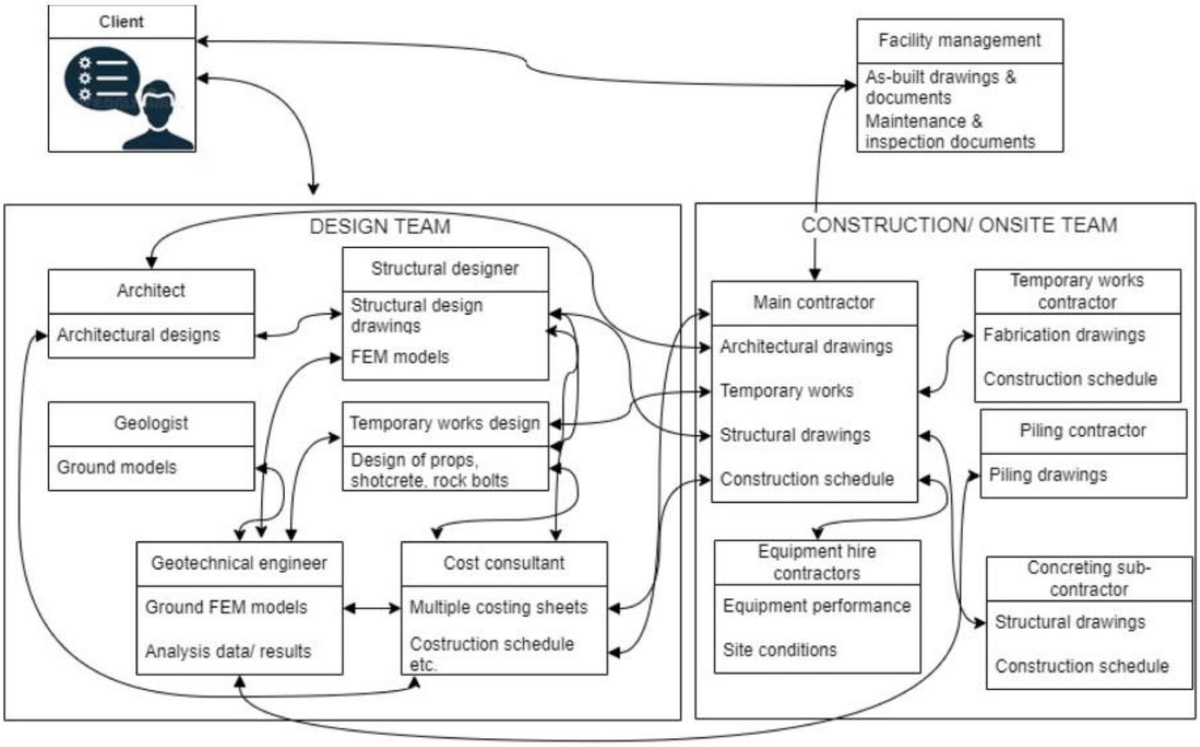


Fig. 3.1: Conceptual model of digital model, digital shadow and digital twin (Babanagar et al. 2025)

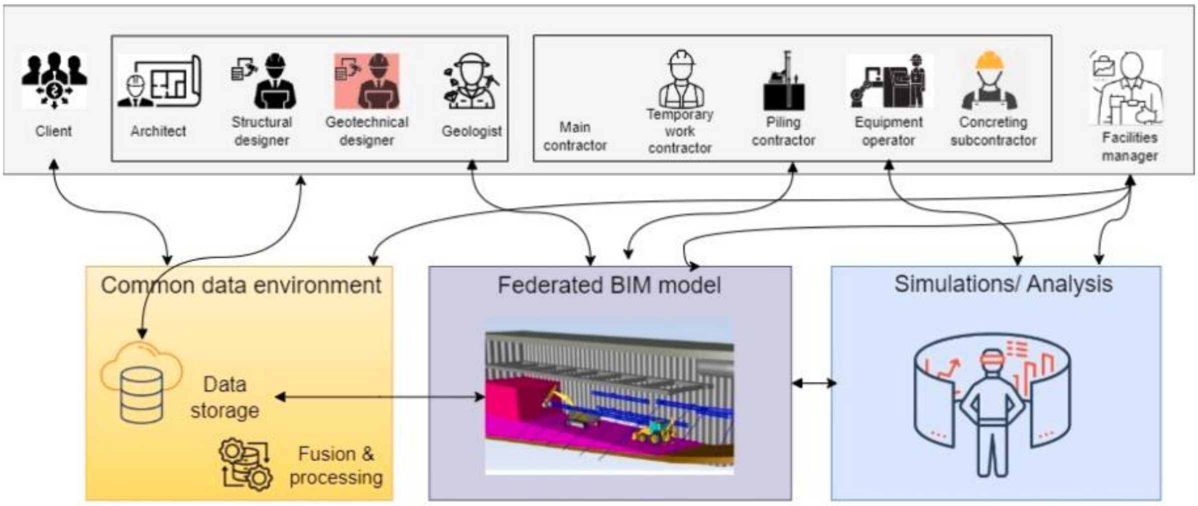
MATURITY DIMENSIONS		Prescriptive									
		Predictive									
		Reflective									
		Descriptive									
FEATURES OF DTREQUIREMENTS ANDCHALLENGES IN OM		Data integration and modelling	Multi-scale visualisation	Real time monitoring	digital model updating	Multi-physics analysis	Safety Assessment	Reliability & sensitivity analysis	Cost optimisation simulations	Risk prognosis	Virtual control and generative design
REQUIREMENTS OF OM AS PER EUROCODE 7	Establish acceptable limits of behaviour as triggers	✔	✔								
	Assess range of possible behaviours	✔	✔								
	Establish monitoring for frequent update to enable contingency plan	✔	✔	✔				✔			
	Rapid monitoring to capture real time change	✔	✔	✔	✔						
	Define at contingency actions when trigger values exceed	✔	✔	✔	✔		✔				
	Continuous monitoring during construction	✔	✔	✔	✔	✔	✔				
	Assessment of monitoring to enable timely contingency action	✔	✔	✔	✔	✔	✔	✔		✔	✔
	Maintain reliability and quality of data	✔	✔	✔	✔	✔	✔	✔			
CHALLENGES IN OM APPLICATION	Insufficient time for design program	✔	✔	✔	✔	✔	✔	✔			
	Iterative recalibrated analysis process	✔	✔	✔	✔	✔	✔	✔			✔
	Contractual issue- sharing of risks and opportunities						✔	✔	✔	✔	
	Apprehensions of reliability and precision of instrumentation						✔	✔		✔	
	Apprehensions about safety of structure					✔	✔	✔		✔	

Fig. 3.2: Synergy between observational method and digital twin (Babanagar et al. 2025)

Fig. 3.3 illustrates the difference between classical information flow and information flow in a BIM project. The digital twin (federated BIM model) represents the center of the whole BIM process.



(a)



(b)

Fig. 3.3: Information flow between stakeholders in a conventional process (a) and a BIM process (b) (Babanagar et al. 2025).

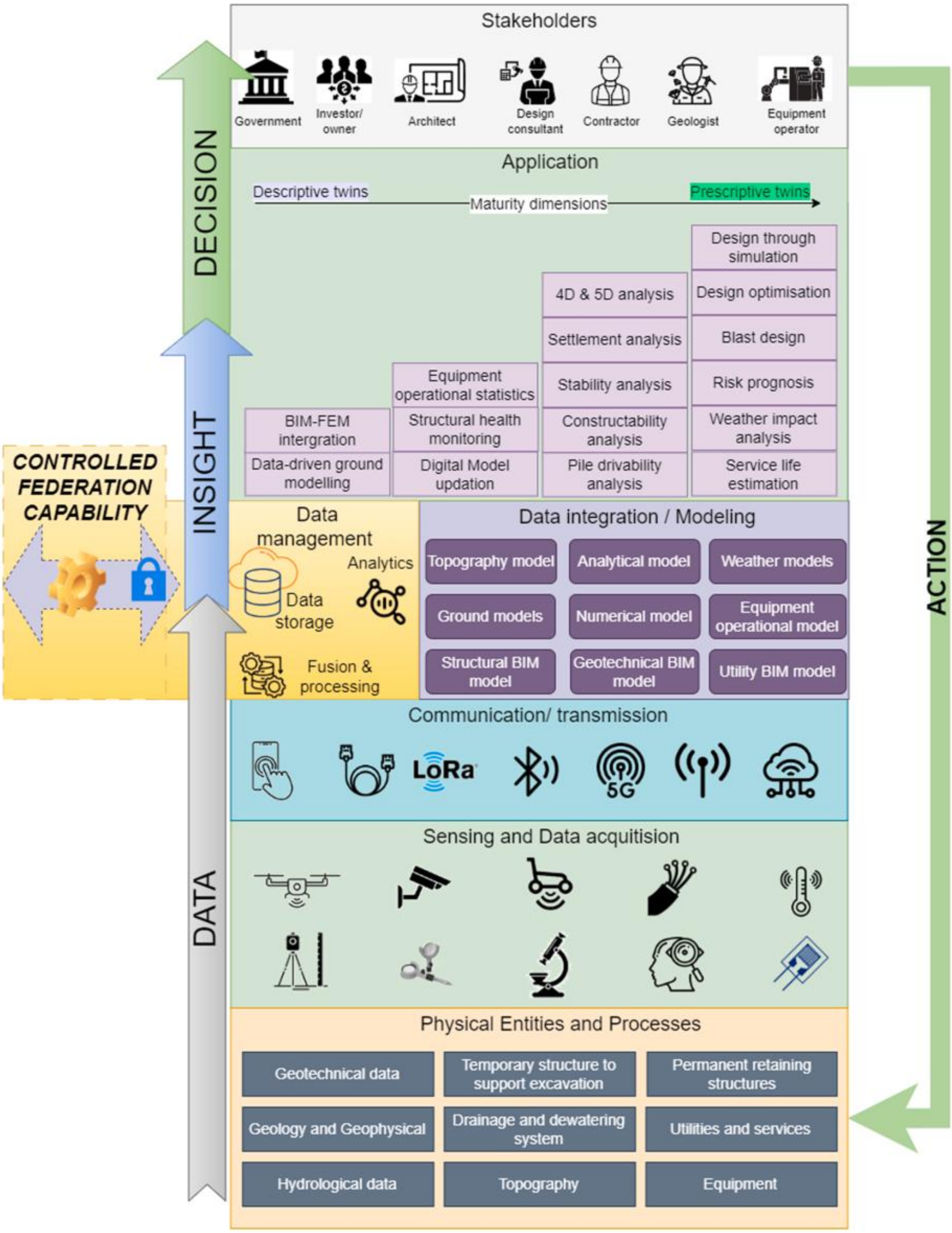


Fig. 3.3: Conceptual model of digital model, digital shadow and digital twin (Babanagar et al. 2025)

4 Benefits of BIM

The application of BIM demands some additional effort (use of complex software incl. training and permanent input of data and information), but is of greatest utility because it reduces overall costs and risks, improves the efficiency and serves as management and communication aid during all stages of construction. The benefits can be described in more detail as follows (see also Ghaffarianhoseini et al., 2017):

- Digital presentation of physical and functional characteristics of a project
- Transfer of data between different software applications
- Central data storage, update and maintenance over whole lifetime
- Management of all kinds of project relevant data like geometry, geographic information, properties of product elements, construction stages, costs, photo documentation, supply chains, accidents etc.
- Complex analysis in case of design changes incl. all consequences
- Standardisation by establishment of data exchange standards in form of IFCs
- Diversity management benefits, like:
    - Facility management
    - Heritage documentation
    - Maintenance
    - Monitoring
    - Quality control
    - Energy management
    - Emergency management
    - Retrofit or renovation planning
- Simulation of construction process in time
- Preventing of schedule delay
- Minimising documentation errors
- Use as marketing and communication tool
- Less staff costs (reduce labour requirements)
- Simplified comprehension of various requirements during project lifecycle
- Offers delivery of material on site just in time
- Optimised collaboration between all involved teams
- Clash detection and early conflict detection
- Optimum exchange of information, evaluations etc. between all partners
- Enables multidisciplinary integration
- Minimising construction risks

Chien et al. (2014) reported that application of BIM has brought the following quantitative benefits:

- Eradication of unforeseen modification by 40%
- Cost estimation with error threshold of only 3%
- 80% reduced generation time
- Saving by clash detection of 10%
- Reduction of project completion time by 7%

McLeamy's curve (Fig. 4.1) shows, that late made decisions will create higher costs and reduce the ability to impact costs. Therefore, early and high-quality ground investigations are important. This is supported by a NEDO study evaluating 5000 buildings, which showed that 50% of the industrial buildings were overran by at least one month of which around 37% of the overruns were due to underground problems (Morin et al., 2014). Consequently, geotechnical information and data have to be incorporated into the BIM process as early as possible to increase the benefit and to reduce risks. The overall time (and consequently also cost) savings using BIM - although a higher investment is necessary at the begin of the project - is illustrated in Fig. 4.2.

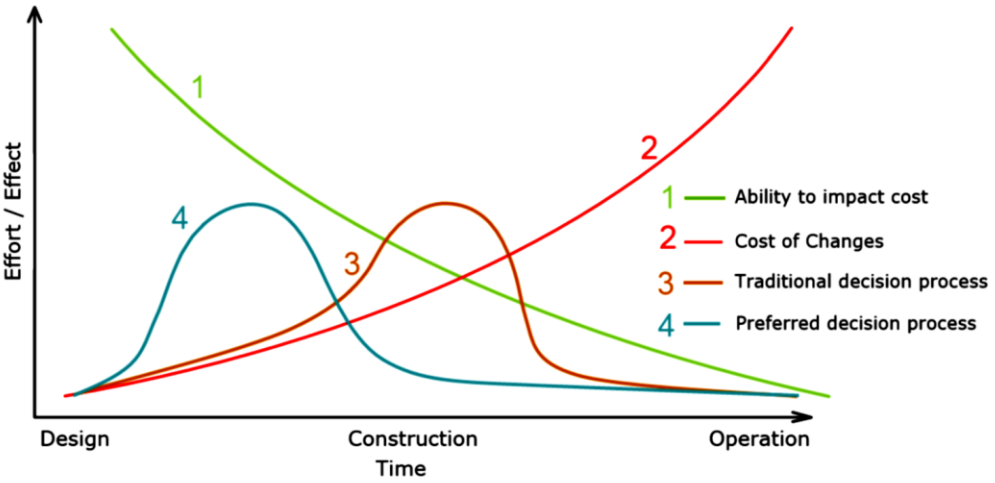


Fig. 4.1: McLeamy's effort curve (Morin et al., 2014)

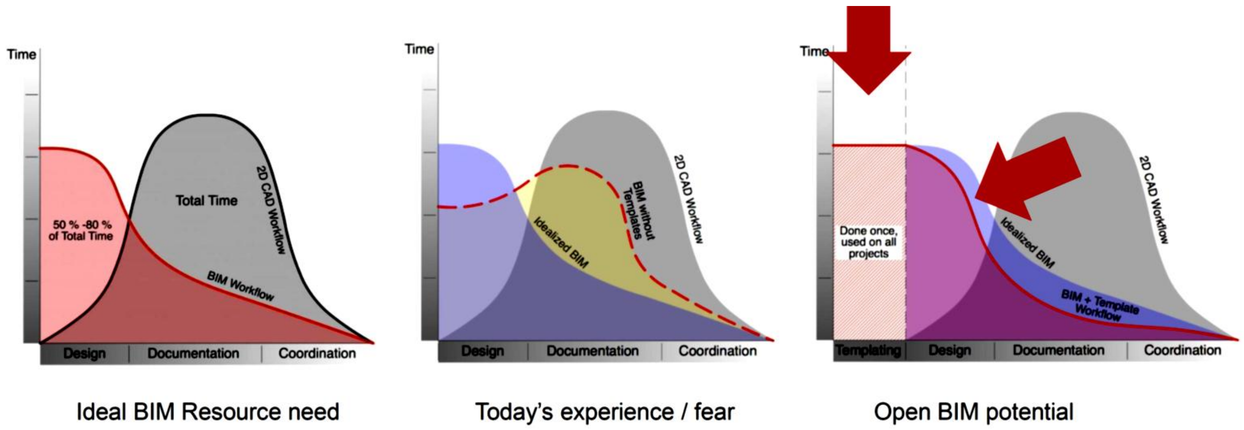


Fig 4.2: Potential time savings using BIM in comparison with traditional workflows (buildingSMART International)

The performance of a BIM project should meet the following requirements (Succar et al. 2012):

- Accurate: Well-defined and able to measure performance at high levels of precision.
- Applicable: Able to be used by all stakeholders across all phases of a project’s lifecycle.
- Attainable: Achievable if defined actions are undertaken.
- Consistent: Yield the same results when conducted by different assessors.
- Cumulative: Set as logical progressions; deliverables from one act as prerequisites for another.
- Flexible: Able to be performed across markets, organisational scales and their subdivisions.
- Informative: Provide ‘feedback for improvement’ and ‘guidance for next steps’ (Nightingale & Mize, 2002, p. 19).
- Neutral: Not prejudice proprietary, non-proprietary, closed, open, free or commercial solutions or schemata.
- Specific: Serve the specific requirements of the construction industry.
- Universal: Apply equally across markets and geographies.
- Usable: Intuitive and able to be easily employed to assess BIM performance.

5 BIM including risk management

According to Kostka & Anzinger (2015) analysing large infrastructure projects in Germany between 1960 and 2014, significant cost overruns were observed, for instance for energy and ITC projects with 136% and 394% on average, respectively and about 40% for building and transportation projects on average. Tab. 5.1 and 5.2 give more corresponding detailed data about projects in Germany and worldwide. To avoid unexpected cost overruns risk management according to ISO 31000 (2018) should be included in BIM (see Fig. 5.1). Leitch (2010) and Olechowski et al. (2016) provide a good introduction into risk management.

Salzmann et al. (2020) explain - on the example of a tunnel construction - how risk management can be included in BIM applying the Monte-Carlo simulation method. Tab. 5.3 shows a list of construction items with their corresponding cost distribution functions including estimated minimum, maximum and most likely costs. Fig. 5.2 and 5.3 illustrate the cost variations according to risks/insecurities.

Further practical applications of risk management for tunnels are provided by Cardenas et al. (2013, 2014) and Van Weyenberge et al. (2016).

Tab. 5.1: Cost overruns for infrastructure projects in Germany between 1960 and 2015 (Kostka & Anzinger, 2015)

Sector	Unfinished Projects *Average Cost Overruns (in %)*	*n*	Finished Projects *Average Cost Overruns (in %)*	*n*	Total *Average Cost Overruns (in %)*	*n*
Building	**29**	**28**	**44**	**59**	**39**	**87**
Construction	35	18	41	50	39	68
Maintenance	18	10	63	9	39	19
Defense Acquisition	**26**	**5**	**87**	**3**	**49**	**8**
Energy	**28**	**1**	**136**	**9**	**126**	**10**
Gas			57	1	57	1
Nuclear	28	1	187	6	164	7
Wind	-	-	24	2	24	2
ICT	**101**	**2**	**394**	**8**	**336**	**10**
Service	101	2	388	5	306	7
Transportation			405	3	405	3
Transportation	**61**	**15**	**33**	**36**	**41**	**51**
Airport	73	2	48	4	56	6
Bridge	-	-	11	2	11	2
Port	80	1			80	1
Rail	27	6	34	6	30	12
Road	17	4	30	20	27	24
Tunnel	364	1	42	2	149	3
Waterway	91	1	57	2	68	3
Other	-	-	**68**	**4**	**68**	**4**
Total	**41**	**51**	**73**	**119**	**63**	**170**

Tab. 5.2: Cost overruns for infrastructure projects worldwide (Kostka & Anzinger, 2015)

	Germany		**Netherlands**		**North Europe**		**West World**	
	Average cost overrun (%)	Sample size (n)	%	n	%	n	%	n
Road	30	20	19	37	21	315	20	537
Rail	34	6	11	26	22	90	34	195
Tunnel/Bridges	27	4	22	15	32	54	33	74
Total	30	30	17	78	22	459	24	806

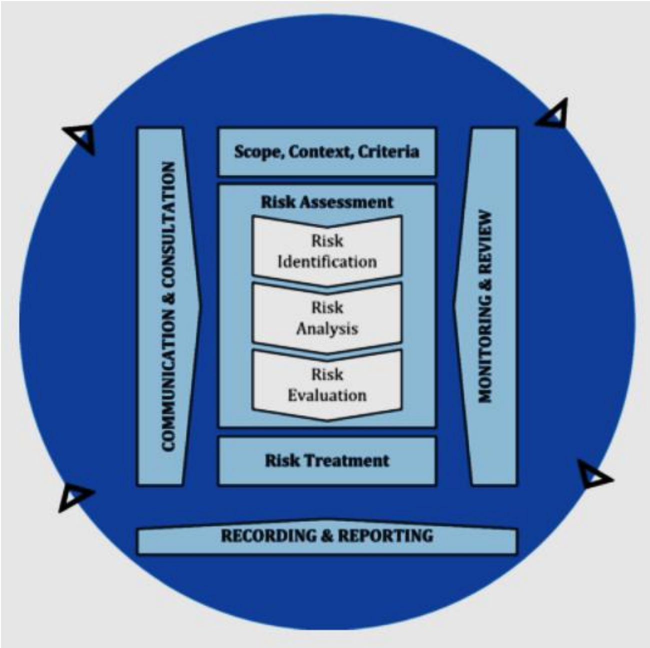


Fig. 5.1: Scheme illustrating the elements of risk management (ISI 31000, 2018)

Tab. 5.3: Tunnel construction items and cost estimates (Salzmann et al., 2020)

NPC 241	Norm Position Catalog	%	Min Mio. $	Likeliest Mio. $	Max Mio. $	Distribution Mio. $	Function
100,00	Formwork / Schalung	80,0%	$14,00	$25,00	$30,00	$23,05	
200,00	Formwork / Schalung	70,0%	$14,00	$20,00	$25,00	$20,33	
300,00	Concrete / Beton	60,0%	$18,00	$22,00	$23,00	$22,28	
400,00	Recesses / Aussparungen	55,0%	$8,00	$12,00	$18,00	$16,52	
500,00	Reinforcement / Bewehrung	50,0%	$11,00	$12,00	$13,00	$11,64	
600,00	Concrete / Beton	40,0%	$8,00	$10,00	$14,00	$9,32	
700,00	Concrete / Beton	40,0%	$6,00	$8,00	$10,00	$9,71	
800,00	Construction / Bauteile	35,0%	$6,00	$7,00	$10,00	$6,54	
900,00	Construction / Bauteile	20,0%	$9,00	$11,00	$12,00	$11,36	
Total Cost	Concrete Constructions		$94,00	$127,00	$155,00	$130,75	

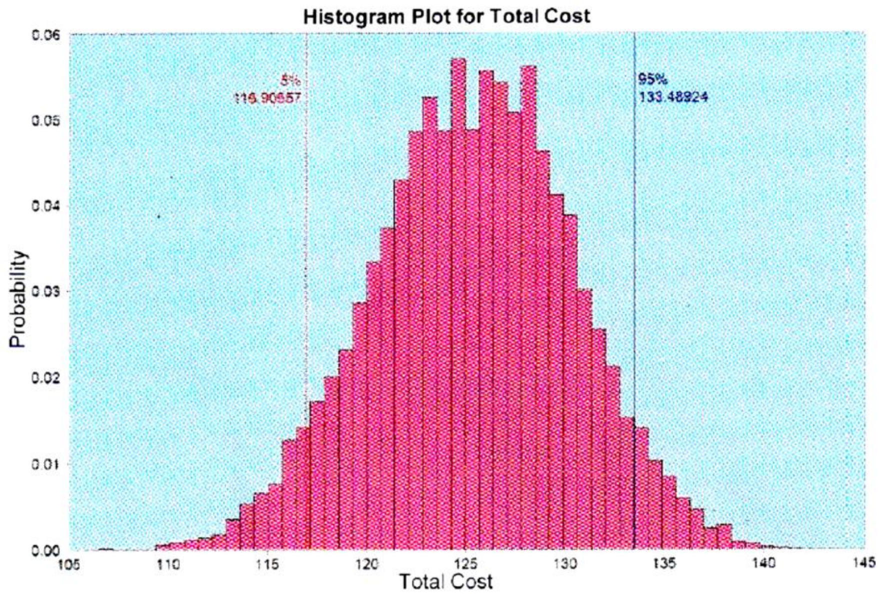


Fig. 5.2: Total cost chart for a tunnel project with probability of occurrence (Salzmann et al., 2020)

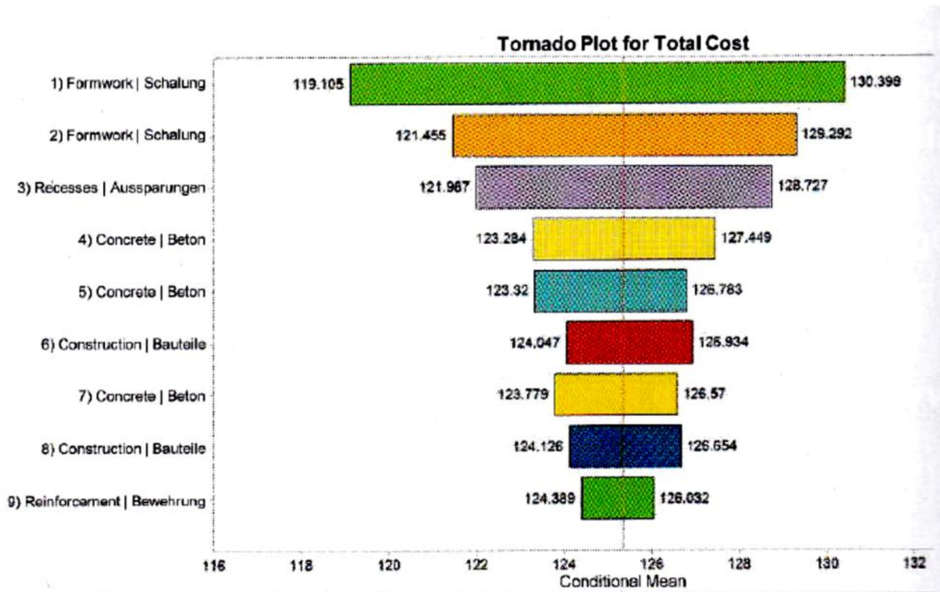


Fig. 5.3: Tornado diagram for costs in millions of dollars of a tunnel project for different items considering their spans (Salzmann et al., 2020)

6 Example

6.1 Highspeed railway system in China (CRBIM, 2015)

Nowadays planning, construction and maintenance of railway systems is managed via BIM. A layer structure is used to improve maintenance, access and expandability. Besides classical BIM elements like buildings (railway stations or bridges) also geotechnical components are involved like subgrade domain, tunnel domain, alignment domain or geology domain (see Fig. 6.1.1). Fig. 6.1.2 illustrates a corresponding spatial IFC concept.

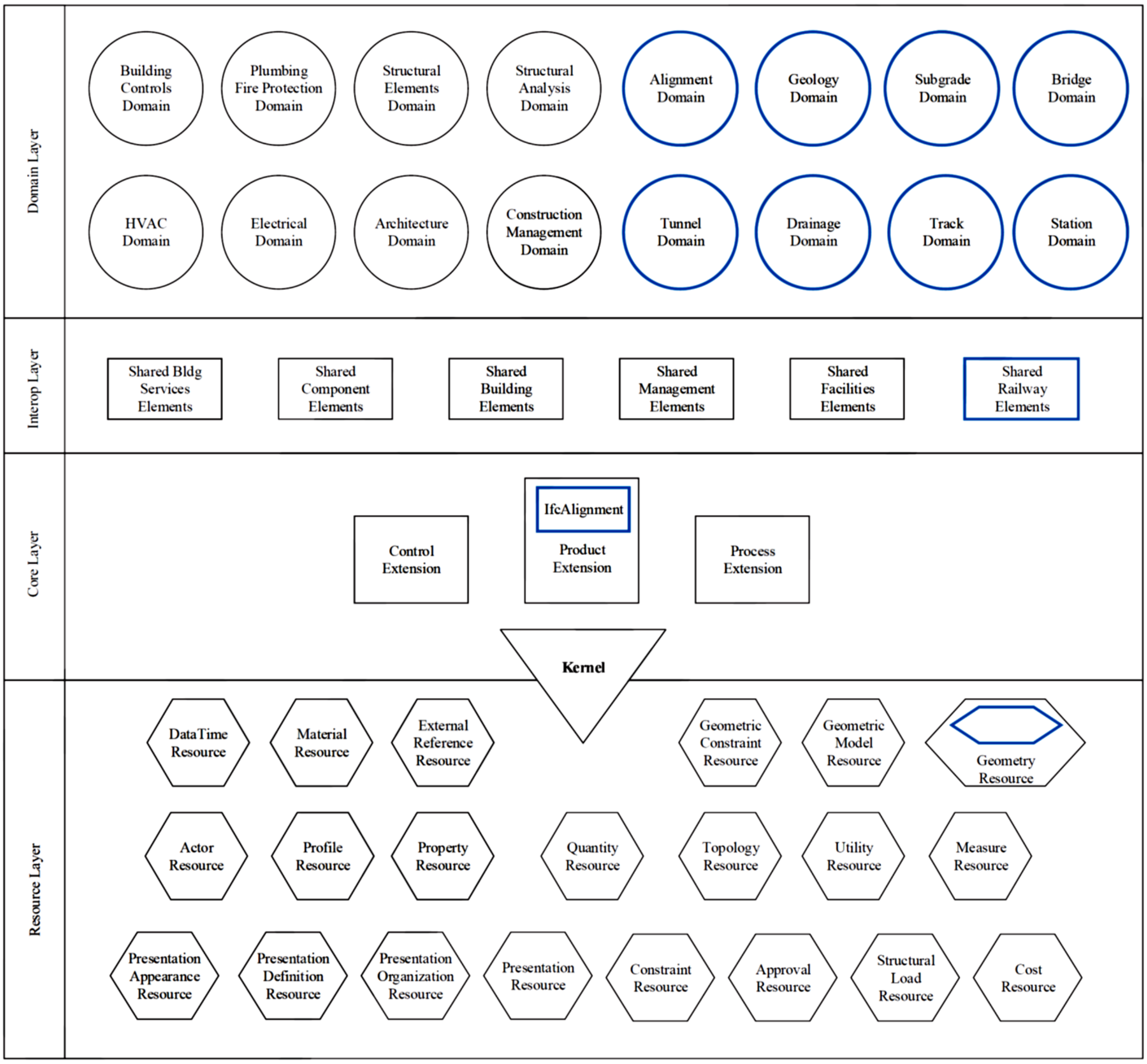


Fig. 6.1.1: Railway BIM layer architecture (CRBIM, 2015)

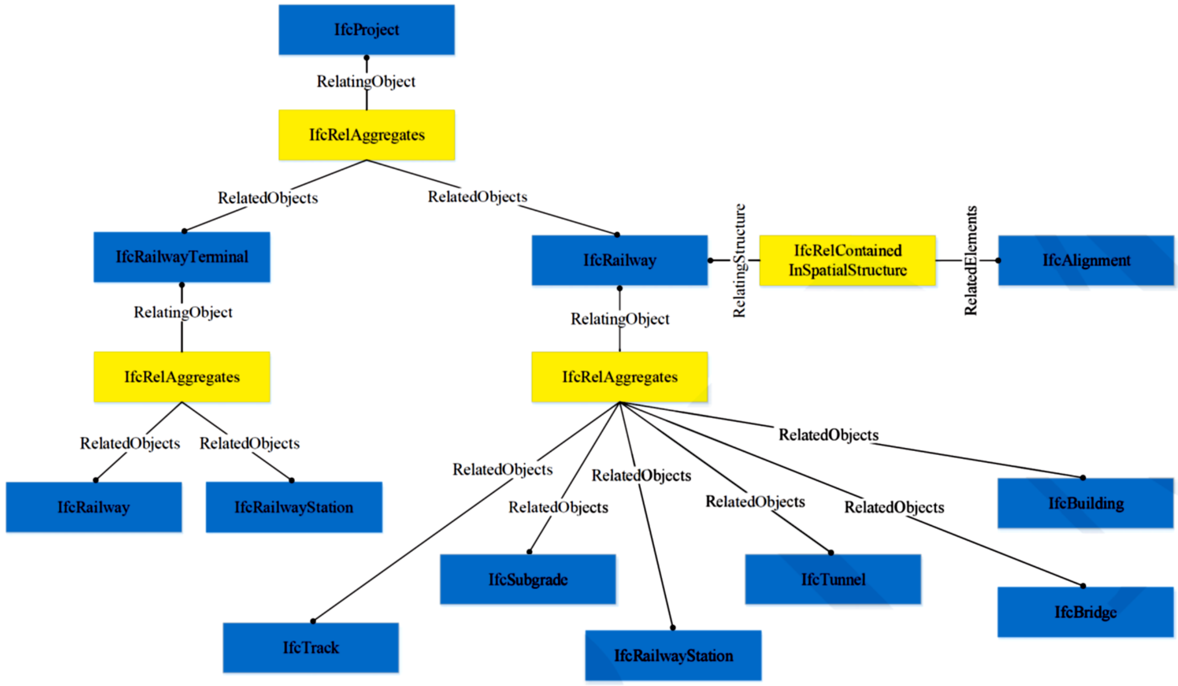


Fig. 6.1.2: Spatial IFC concept (CRBIM, 2015)

Complex BIM for railway construction and maintenance contains amongst others the following components and steps:

- Determination of optimum railway routes based on optimisation algorithms
- Digital elevation model
- Geological model with all relevant features of ground and sub-surface structures
- Any kind of documents for dimensioning incl. numerical simulations
- Information about existing infrastructure, landscape and vegetation in the considered area
- Information about rock and soil parameters
- Weather and groundwater conditions in the considered area
- Complete construction process for tunnels, bridges, stations, foundations etc.
- Complete information for any kind of building incl. electricity, telecommunication, water supply etc.
- Photo and video documentation of the construction process
- Properties, dimensions and origin of each construction element
- Results of in-situ measurements and lab tests
- Data exchange between BIM and construction machinery
- Time line and costs
- Any kind of clashes, delays, accidents etc.
- Any kind of documents, certificates, data sheets, invoices etc. of used products

Exemplary, Fig. 6.1.3 and 6.1.4 give impressions about the visualisation potential of BIM for railway projects in China (see also Borrmann et al. (2017) for further applications of BIM for infrastructure).

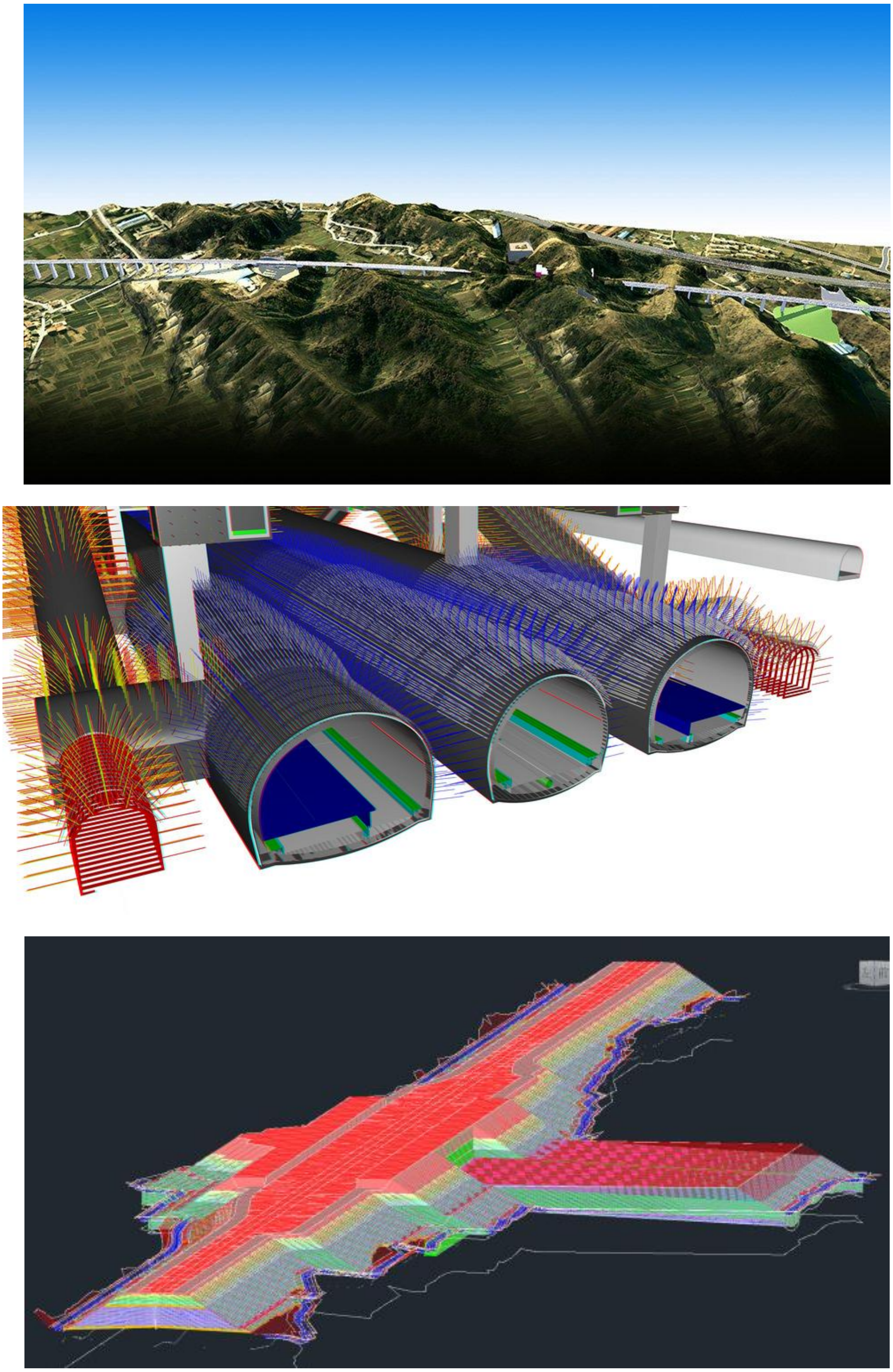


Fig. 6.1.3: Selected visualisations from railway BIM (part 1) (CRBIM, company material)

Fig. 6.1.4: Selected visualisations from railway BIM (part 2) (CRBIM, company material)

6.2 BIM for underground constructions (DAUB, 2019)

DAUB (2019) has published a recommendation how BIM can be used for underground constructions. The general recommendation is explained by using descriptive illustrations. Fig. 6.2.1 illustrates how several BIM submodels (geotechnical model, surface infrastructure model, tunnel model etc.) are combined to set-up a complex numerical model to perfom a subsidence prediction. Fig. 6.2.2 shows the 5-dimensionality of a BIM project, which includes (a) a 3d spatial model, (b) a schedule of the construction process and (c) the cost development as a timeline.

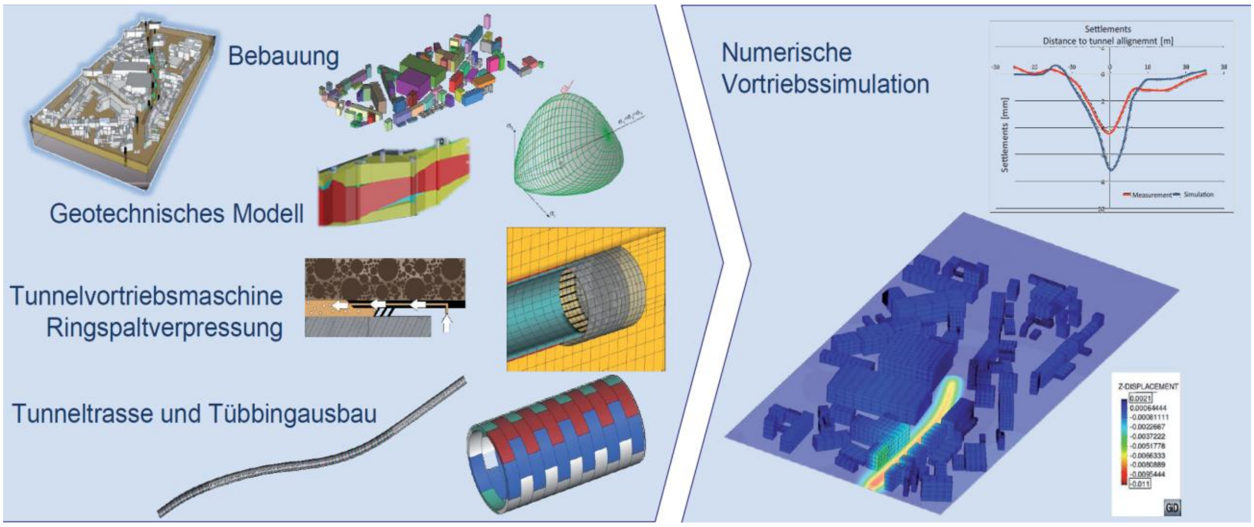


Fig. 6.2.1: BIM Submodels used for numerical subsidence prediction (DAUB, 2019)

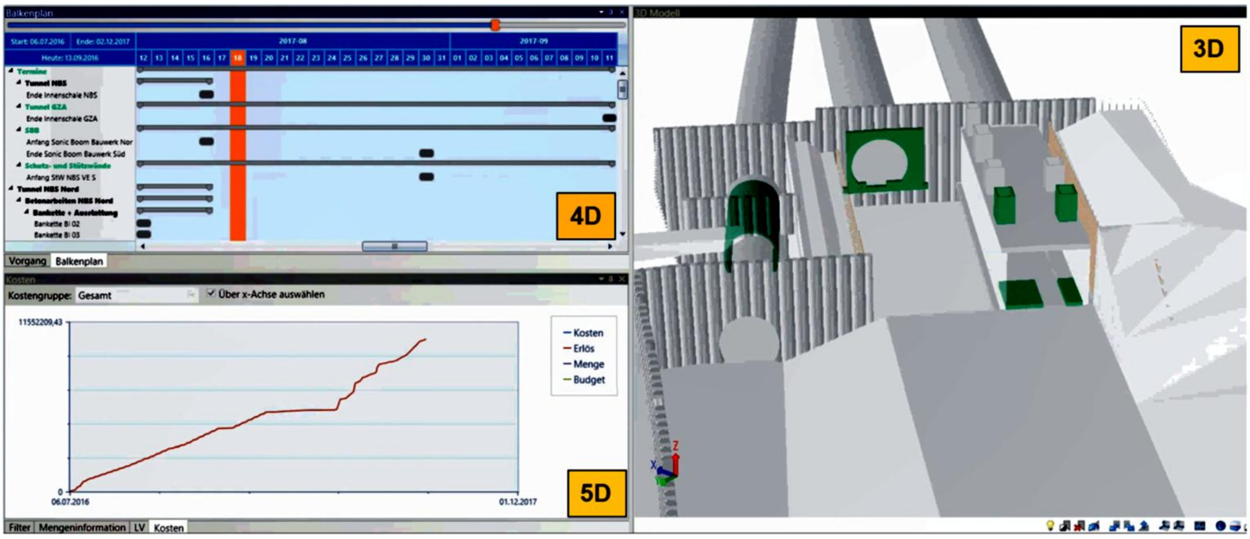


Fig. 6.2.2: 5-dimensionality of a BIM project (3D in space, construction schedule (4D) and cost-development (5D)), (DAUB, 2019).

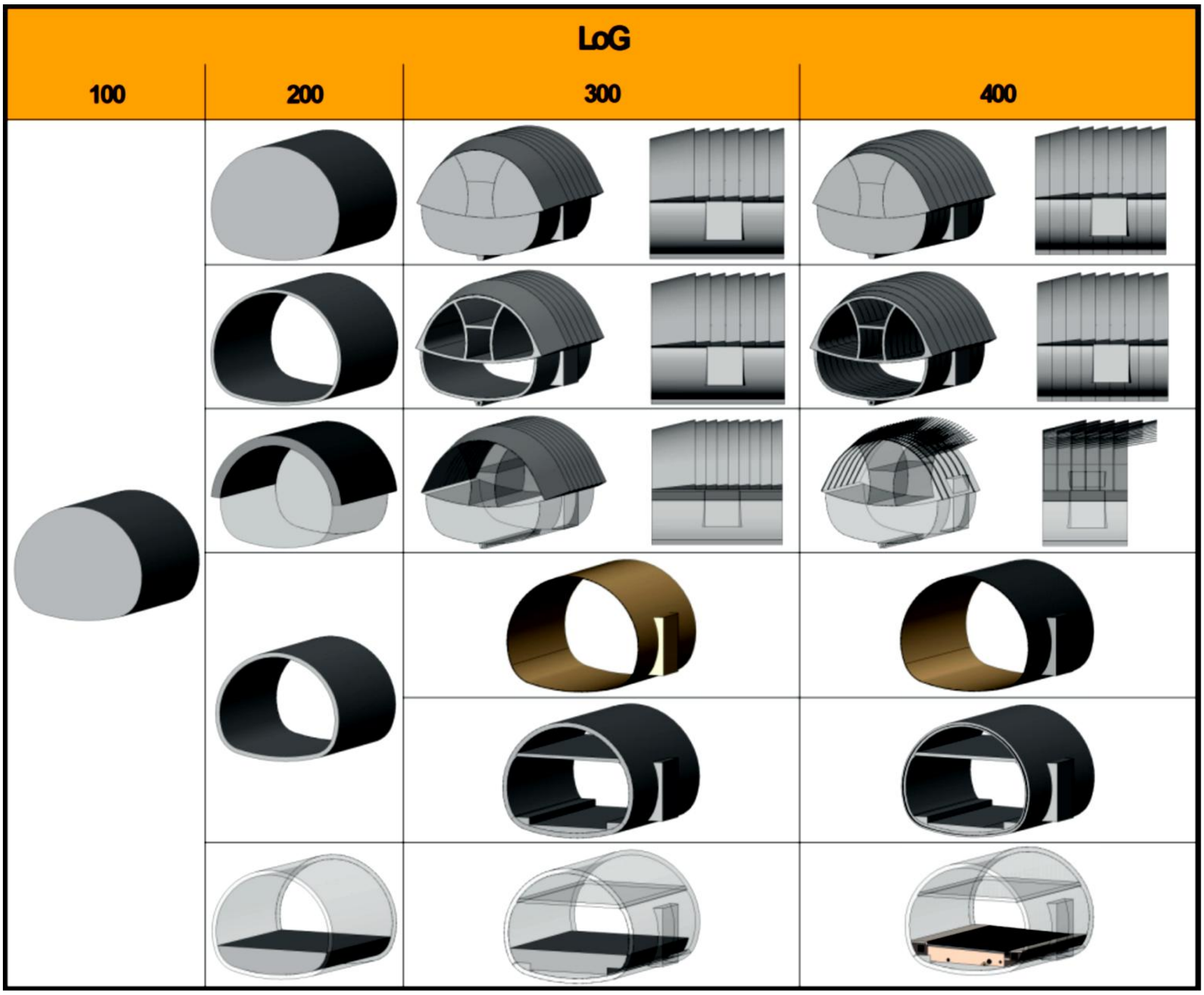


Fig. 6.2.3: Illustration of LoG, exemplary explained using a tunnel construction (DAUB, 2019)

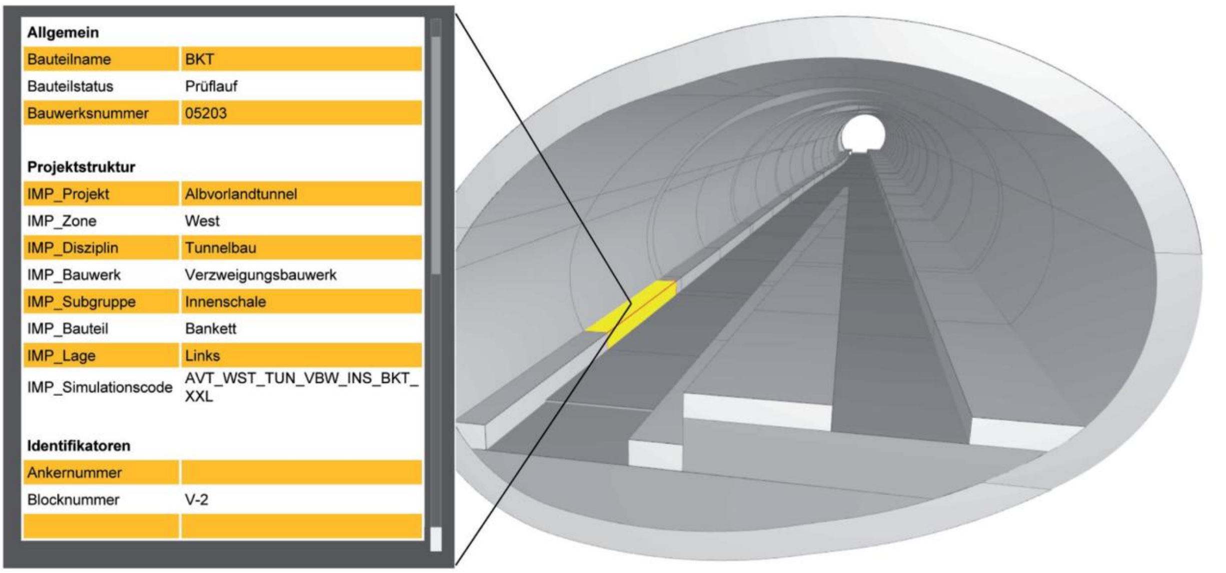


Fig. 6.2.4: Example for attributes of a specific object of a model (DAUB, 2019)

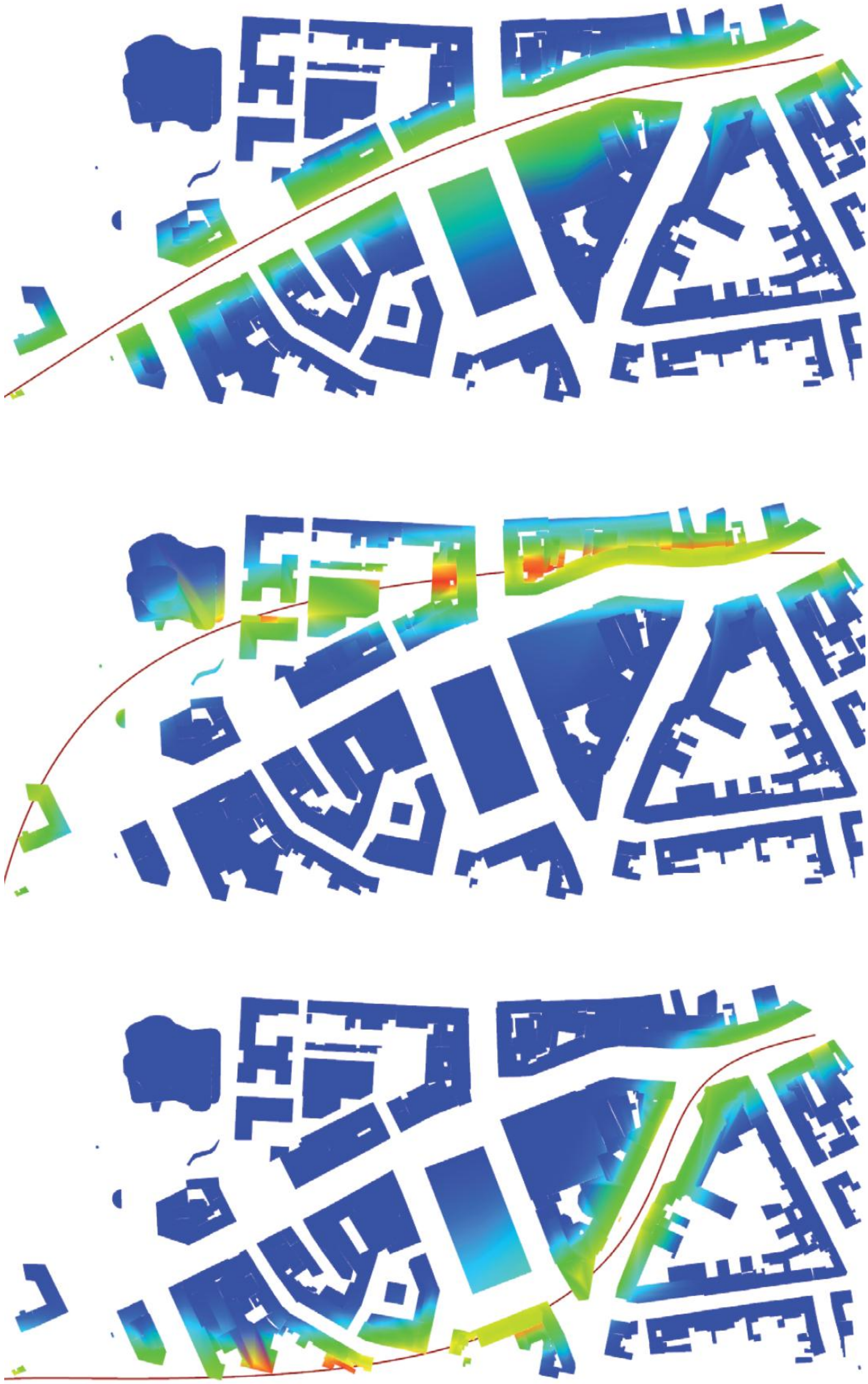


Fig. 6.2.5: Comparison of different variants to find optimum solution for a tunnel route, shown is the predicted surface subsidence for three different variants (DAUB, 2019)

Especially in densely populated areas like big cities any planned underground acticity has to consider already existing infrastructure. Existing BIM models can be used or the existing structures have to be incorporated in a new set-up BIM project in advance to avoid conflicts. Fig. 5.2.6 shows a BIM based presentation of existing infrastructure at a crossing in London.

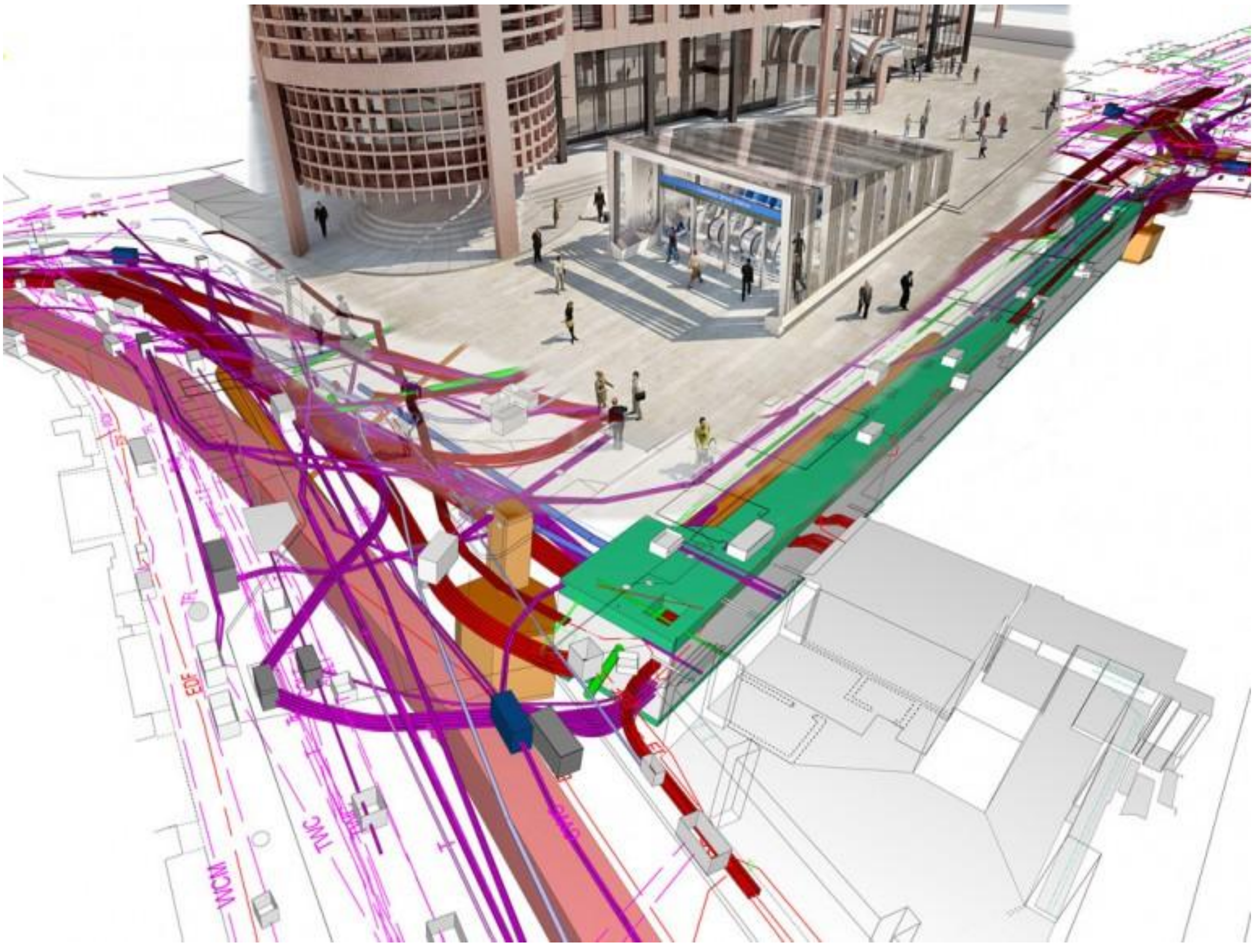


Fig. 5.2.6: BIM based presentation of existing underground infrastructure at a crossing in London (Crossrail in DAUB, 2019)

6.3 Kleiweg Sewer Project (Nie, 2019)

Nie (2019) describes the use of BIM including GIS for a sewer renewal project in the Netherlands. Fig. 6.3.1 gives an overview about the project. The BIM model consists of several layers, like:

- Terrain
- Buildings
- Trees
- Light poles
- Electricity network
- Telecom network
- Television cable

- Drinkwater system
- Gas system
- Current Sewer System
- New Sewer System
- Sewage system
- Stressts
- Water

Such a BIM model can be used to avoid collision of the new sewer system with existing underground networks, to optimize the new sewer system, but also to act as high-precision orientation for any kind of earthworks, for instance GPS based running of excavators.

Fig. 6.3.1: BIM model for Kleinweg Sewer Project with all layers (Nie, 2019)

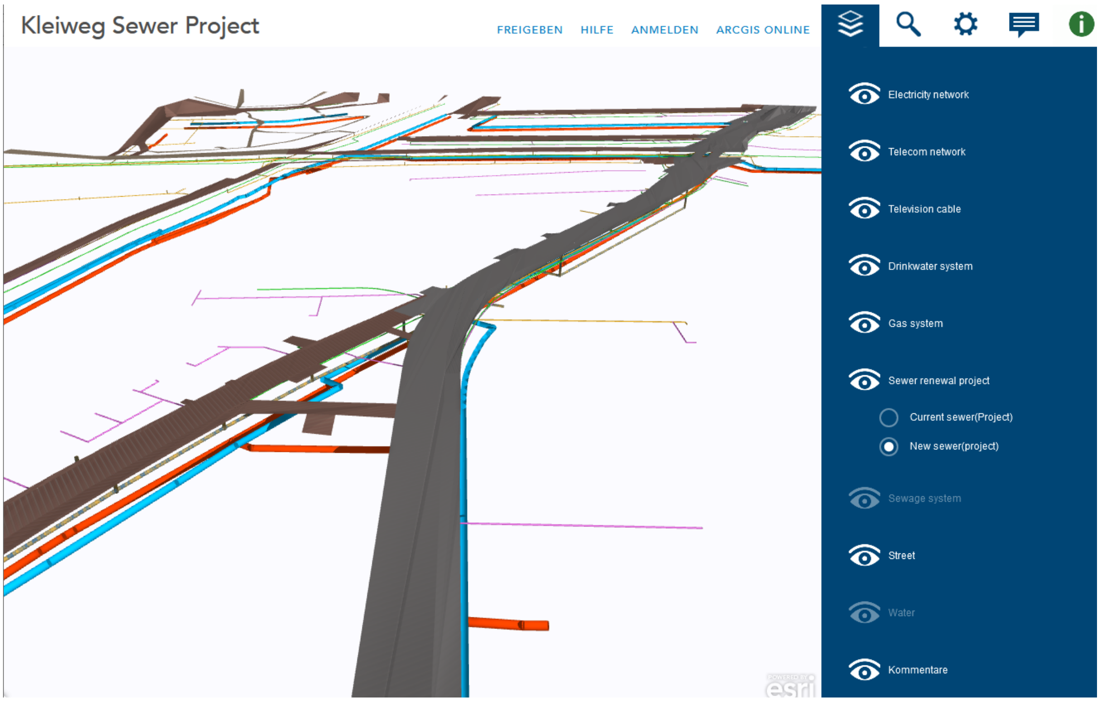


Fig. 6.3.2: BIM model for Kleinweg Sewer Project with streets and underground network layers only (Nie, 2019)

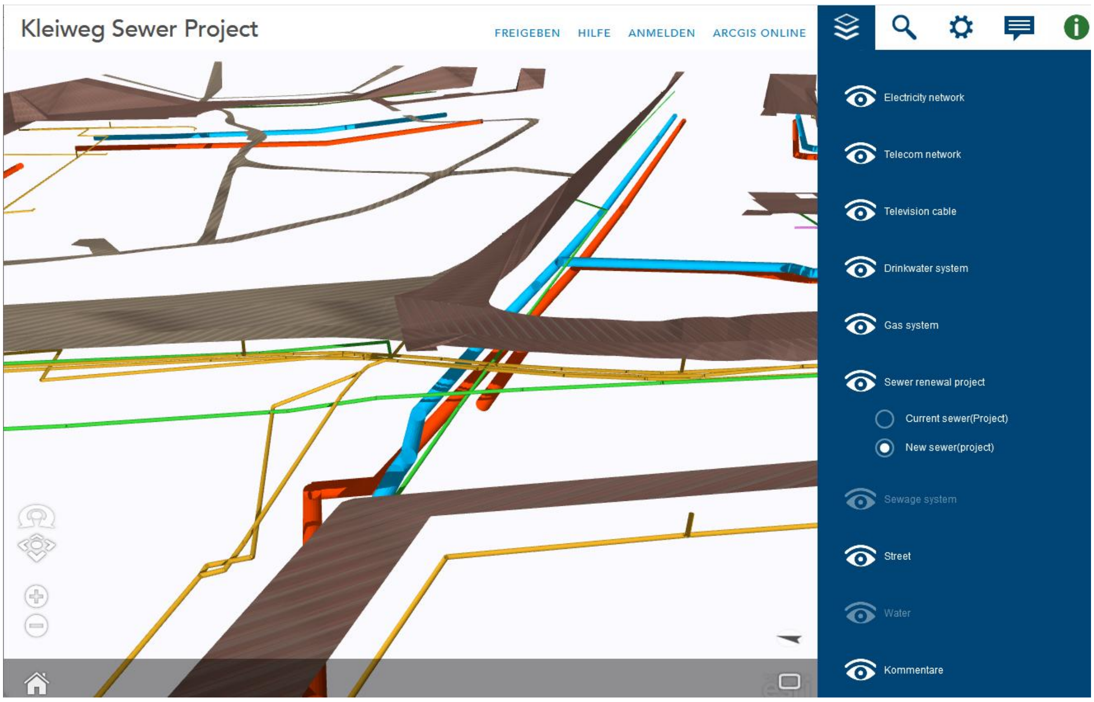


Fig. 6.3.3: BIM model (specific detailed view) for Kleinweg Sewer Project with streets and underground network layers only (Nie, 2019)

6.4 Metro Project Melbourne (Huang et al., 2022)

Huang et al. (2022) describes a BIM application for an underground metro station considering different LOD according to construction stage and application scenarios. Fig. 6.4.1 provides an overview.

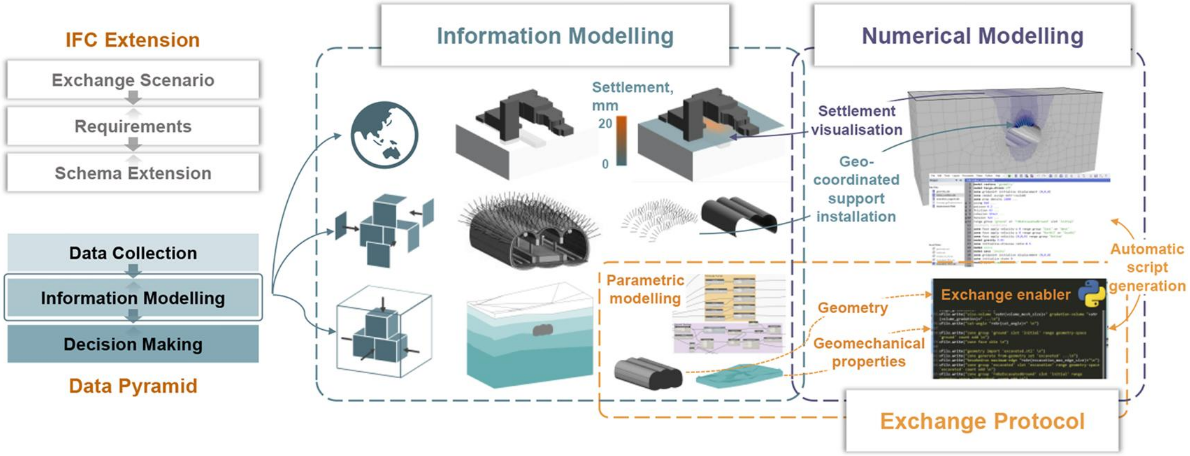


Fig. 6.4.1: Overview about BIM application for underground metro station (Huang et al. 2025)

7 References

Allplan (2016): BIM-Compendium Theory and Practise, Allplan Deutschland GmbH, 340 p.

Babangar, N. et al. (2025): Digital twins for urban underground space, Tunneling and Underground Space Technology, 155: 106140

Borrmann, A.; König, M.; Braun, M.; Elixmann, R.; Eschenbruch, K.; Hausknecht, K.; Hochmuth, M.; Liebich, T.; Scheffer, M. & Singer, D. (2017): Wissenschaftliche Begleitung der BMVI Pilotprojekte zur Anwendung von BIM im Infrastrukturbau, Bundesministerium für Verkehr und digitale Infrastruktur, 148 p.

Bradley, A.; Li, H.; Lark, R. & Dunn, S. (2016): BIM for infrastructure: an overall review and constructor perspective, *Automation in Construction*, 71(2): 139-152

Cardenas, I.C.; Al-jibouri, S.S.H.; Halman, J.I.M. & van Tol, F.A. (2013): Capturing and integration knowledge for managing risks in tunnel works, *Risk Analysis*, 33(1): 92-107

Cardenas, I.C.; Al-jibouri, S.S.H.; Halman, J.I.M.; van de Linde, W. & Kaalberg, F. (2014): Using prior risk-related knowledge to support risk management decisions: lessons learnt from a tunnelling project, *Risk Analysis*, 34(10): 1923-1943

Chapman, D. et al. (2020): BIM for the underground - an enabler for trenchless construction, Underground Space, 5: 354-361

Chien, K.F.; Wu, Z.-H. & Huang, S.-C. (2014): Identifying and assessing critical risk factors for BIM projects: emprical study, *Automation in Construction*, 45: 1-15

CRBIM (2015): Railway BIM data standard, Version 1.0, China Railway BIM Alliance, CRBIM1002-2015, 218 p.

DB AG (2019): BIM strategy – Implementation of Building Information Modeling (BIM) in the Infrastructure Division of Deutsche Bahn AG, 44 p., https://www.deutschebahn.com/resource/blob/4114234/f17c340682cd9e8f6bfe3faae86e0f52/BIM-Strategy-Deutsche-Bahn-en-data.pdf, last accessed: 02.11.2020.

DAUB (2019): Digitales Planen, Bauen und Betreiben von Untertagebauten, BIM im Untertagebau, Deutscher Ausschuss für Unterirdisches Bauen & German Tunneling Committee, May 2019

DVW (2019): Leitfaden Geodäsie und BIM, DVW-Merkblatt 11-2019

Ghaffarianhoseini, A.; Tookey, J; Ghaffarianhoseini, A.; Naismith, N.; Azhar, S.; Efimova, O. & Raahemifar, K. (2017): Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges, *Renewable and Sustainable Energy Reviews*, 75: 1046-1053

Huang, M.Q. et al. (2022): Multi-LOD BIM for underground matro station: Interoperability and design-to-design enhancement, Tunneling and Underhround space Technology, 119: 104232

IEC-31010 (2019): Risk Management - Risk assessment techniques, IEC-31010:2019.

ISO-31000 (2018): Risk management – Guidelines, ISO-31000:2018.

Kostka, G. & Anziger, N. (2015): Large infrastructure projects in Germany: a cross-sectoral analysis, Hertie School of Governance, 24 p.

Leitch, M. (2010): ISO 31000:2009 - the new international standard on risk management, *Risk Analysis*, 30(6): 887-892

Mary, E.C. (2019): A cloud-based architecture for BIM as an asset for project management, Master Thesis, University of Waterloo

Möller, O. & Mahutka, K.-P. (2018): BIM in der Geotechnik – Konzeptpapier, Hochschule 21, Buxtehude, Technical Report no. 10, 18 p.

Morin, G.; Hassall, S. & Chandler, R. (2014): Case study – the real life benefits of geotechnical building information modelling, Advances in Soil Mechanics and Geotechnical Engineering, Volume 3: *Information Technology in Geo-Engineering*, IOS Press, 95-102

Morin, G. (2018): Geotechnical BIM: Applying BIM principles to the subsurface, Autodesk University, TR-21042, 10 p.

Nie, S. (2019): 3D BIM-GIS for underground network management, Master Thesis, University of Twente (NL)

Obergriesser, M. & Borrmann, A. (2012): Infrastructural BIM standards – Development of an Information Delivery Manual for the geotechnical infrastructural design and analysis process, eWork and eBusiness in Architecture, *Engineering and Construction*, Taylor & Francis, 581-587

Olechowski, A.; Oehmen, J.; Seering, W. & Ben-Daya, M. (2016): The professionalization of risk management: What role can the ISO 31000 risk management principles play? *Int. J. Project Management*, 34(8): 1568-1578

Salzmann, R. et al. (2020): Manageable complexity – BIM and risk-based construction controlling in tunnelling, *Tunnel*, 5: 40-49

Succar, B. (2009): Building information modelling framework: A research and delivery foundation for industry stakeholders, *Automation in Construction*, 18(3): 357-375

Succar, B.; Sher, W. & Williams, A. (2012): Measuring BIM performance: Five metrics, *Architectural Engineering and Design Management*, 8(2): 120-142

Tawelin, L.R. & Mickovski, S.B. (2016): The implementation of geotechnical data into the BIM process, *Procedia Engineering*, 143: 73-741

Van Weyenberge, B.; Deckers, X.; Caspeele, R. & Merci, B. (2016): Development of a risk assessment method for life safety in case of fire in rail tunnels, *Fire Technology*, 52: 1465-1479