Germany's Governmental BIM Initiative – The BIM4INFRA2020 Project Implementing the BIM Roadmap

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Abstract. The technology of Building Information Modeling (BIM) promises a significant increase in productivity in the design, construction and operation of buildings and infrastructure facilities. In the entire world, the AEC industry is starting to transform itself by moving from 2D drawings to digital building models that do not only represent 3D geometry of the building components, but also all the non-geometric data required throughout the building's lifecycle. As this technological change has an impact on all stakeholders of the AEC in a fundamental way, a carefully planned transition is necessary to avoid economical damage. In many countries around the world, government-driven initiatives are underway to initiate the necessary changes. Also Germany is preparing the transition to BIM-based workflows in its AEC industry. In 2015, the German Ministry of Transport and Digital Infrastructure defined a comprehensive roadmap for the stepwise introduction of BIM methods with the goal to make BIM mandatory for federal infrastructure projects in 2020. The authors present the outcomes of the large-scale project BIM4INFRA2020 initiated by the government that helped to pave the way towards the German BIM mandate through a number of measures, including the precise definition of the BIM implementation on the basis of well-defined use cases, the guidance and supervision of a number of carefully selected pilot projects, the creation of extensive guidelines and handouts, and the formulation of measures to be taken by industry and government to overcome yet existing hurdles.

Keywords: BIM roadmap · BIM use cases · BIM pilot projects · BIM mandate

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1 Introduction

The technology of Building information modeling (BIM) promises a significant increase in productivity in the design, construction and operation of buildings and infrastructure facilities (Borrmann et al. 2018). In the entire world, the AEC industry is under transformation - overcoming the conventional inefficient and error-prone practices based on 2D drawings by moving to the work with digital building models. These digital models that do not only represent 3D geometry of the building components, but also all the non-geometric data required throughout the building's lifecycle. As this technological shift has a significant impact on all stakeholders of the AEC industry in a fundamental way, a carefully planned transition is necessary to avoid economical damage.

In many countries around the world, government-driven initiatives are underway to initiate the necessary standards, guidelines and contract templates. The most prominent example is the United Kingdom where in 2010 the Cabinet office has initiated the BIM initiative with April 2016 demarking the official starting point for mandatory use of BIM in all public projects (Cabinet Office 2011). During the preparation process, a large number of carefully elaborated guidelines and standards defining BIM processes, contents and handover have been developed. Other examples of government-driven national BIM initiatives include Finland (Senate Properties 2007), Sweden (Statsbygg 2013), Denmark (BIPS 2013), the Netherlands (Rgd 2013) and Singapore (BCA 2013).

2 German Roadmap for Establishing BIM

Like many other industrialized countries, also the German government is pushing forward the transition to BIM-based workflows in its AEC industry. In 2014, after analyzing the reasons of failure in a number of large-scale construction projects, a national commission recommended as one measure for reducing projects risks to make extensive use of digital methods such as BIM in order to make the complexity of large projects manageable (BMVI 2013).

In consequence, the German Ministry of Transport and Digital Infrastructure has developed a strategic plan for the stepwise introduction of BIM methods in public construction projects. The resulting BIM roadmap ("BIM-Stufenplan") has been published in December 2015 (BMVI 2015).

It defines the following general goals:

- Increase in planning accuracy and reduction in cost overruns
  - visualization of planning alternatives
  - less design errors by collision detection and enforced collaboration between stakeholders
  - precise assessments of cost increases caused by owners' change requests
  - improved reliability of construction processes by simulation of construction sequences

- Improved communication with the public
  - comprehensible visualization of construction projects for maximum transparency
- Optimization of life-cycle costs
  - simulation of life-cycle costs (including operation and maintenance costs)
  - provision of the digital model to the owner as a basis for facility management

The BIM roadmap provides a rough definition of "Niveau 1" for BIM-based project delivery encompassing the following key features:

- project procurement and delivery based on ISO 19650
- defining employer's information requirements (EIR) in each project providing the specification of use cases, model extent, as well as object and attribute catalogues
- creation of a BIM Execution Plan (BEP) by the supplier detailing the way the EIR are proposed to be satisfied
- implementation of the principle of federated BIM model management according to ISO 19650
- usage of a common data environment according to ISO 19650
- use of open data exchange standards (mainly IFC, but also OKSTRA and GAEB)
- formal checking of BIM models for fulfilment of the EIRs

Apart from these characteristics, the general execution of construction projects is kept as-is to the largest extent possible. This includes the legal frameworks as well as the remuneration regulations (Honorarordnung für Architekten und Ingenieure – HOAI). These decisions were taken to allow an easy and hurdle-free transition to BIM-based project execution. For a future Niveau 2, changes in laws and remuneration regulations might be required.

The defined Niveau 1 is expected to be implemented in federal infrastructure projects starting in December 2020. To reach this goal, three phases have been defined:

- Phase 1: 2015 – 2017: Preparation Phase
- Phase 2: 2017 – 2020: Extended Pilot Phase
- Phase 3: from 2020: BIM Niveau 1 for new projects

During the preparation phase (Phase 1), pioneer pilot projects were conducted (Borrmann et al. 2016) BMVI (2014), standardization activities were started and programs for professional training were initiated. This paper reports on the outcomes of Phase 2, which was mainly driven by the large-scale project BIM4INFRA2020.

3 The BIM4INFRA2020 Project

To implement phase 2 of the BIM roadmap, the German Ministry of Transport tendered a large-scale project, which was won by the BIM4INFRA2020 consortium. The consortium consisted of Planen Bauen 4.0, Technical University of Munich, Ruhr-University Bochum, HOCHTIEF ViCon, AEC Deutschland, Obermeyer Planen + Beraten, WTM Engineers, Max Bögl, and Kapellmann & Partner, thus bringing together a broad range of backgrounds, views and expertise from academia, BIM

consulting, design offices, construction companies and lawyers. The consortium's work started in January 2017 and ended in August 2019.

The workplan of BIM4INFRA2020 consisted of the following main items:

- Definition of the BIM 2020 scenario
- Legal compliance on BIM project execution
- Guidance and supervision of BIM pilot projects
- Publication of guidelines for BIM implementation
- Development of a database strategy

The following sections report on the main outcomes of the individual work packages. The legal opinions are excluded as they are of limited value for the international audience. The interested reader is referred to (BIM4INFRA 2018a).

4 Definition of the BIM 2020 Scenario

To allow the market to prepare for the upcoming BIM mandate, a clear specification of the expected BIM execution of construction projects was required. The German Ministry of Transport asked BIM4INFRA2020 for the specification of three different scenarios named "Entry", "Raise", and "High performance", with both, increasing implementation effort, but also increasing benefits (Fig. 1).

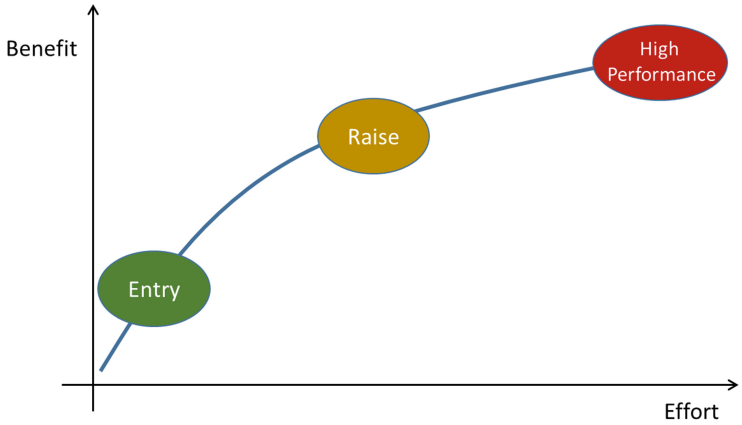

Fig. 1. The three scenarios "Entry", "Raise" and "High performance" with increasing effort, but also increasing benefit.

BIM4INFRA2020 decided to design the scenarios by defining on the one hand a framework of fixed boundary conditions that hold for each of the three scenarios, and on the other hand a flexible part based on a selection of BIM use cases that is specific for each scenario. The proposed rigid framework consists of the following boundary conditions that follow the aforementioned definition of BIM Niveau 1:

- Use of Common Data Environment
- Provision of Employer's Information Requirements
- Provision of BIM Execution Plan
- Consistent use of Classification Systems
- Procurement and project execution according to ISO 19650

These boundary conditions provide the basis for any sound BIM implementation and are thus integral part of all three scenarios.

The three scenarios are distinguished by the selection of mandatory BIM use cases. The concept of BIM use cases as the primary way of describing the purpose of apply the methodology has been developed at PennState (Kreider and Meisner 2013) and is adopted widely in the entire world. BIM4INFRA2020 defined 20 standard use cases and provided a detailed description for each of them. The complete list of use cases is depicted in Fig. 2.

1. Initial State Modeling	11. Bill of quantities / Tendering
2. Design option analysis	12. 4D Execution Planning
3. Visualization	13. Logistics planning
4. Simulation and dimensioning	14. Drawing Generation: Detailed Design
5. Coordination	15. Construction Progress Monitoring
6. Design Progress Control	16. Change Management
7. Drawing Generation: Preliminary Design	17. Billing
8. Safety Design	18. Issue Management
9. Design Approval	19. As-built documentation
10. Cost estimation	20. Operation and Maintenance

Fig. 2. List of standard use cases defined by BIM4INFRA2020

The use cases are associated with dedicated design/construction/operation phases of a building's lifecycle, thus providing a link to the current project execution phases, also with respect to contractual and honorarium issues.

The selection of the use cases for an individual scenario was based on an intense effort-benefit analysis. A panel of 40 experts consisting of owners, operators, designers and contractors was involved in a survey to assess the benefit of each use case as well as the expected effort that is required, both in terms of investment (including organizational changes, training, investment in hard- and software etc.) as well as in terms of increased effort in project execution. The scoring scale ranged from 0 to 3. The aggregated results of the survey are depicted in Fig. 3.

As shown in Fig. 3, the ratio between benefit and effort was calculated for each use case. Subsequently, thresholds were defined for associating a use case with a certain scenario. Use cases with a benefit-effort ratio over 1.5 were assigned to the "Entry" scenario, uses cases with a benefit-effort ratio between 1.2 and 1.5 were assigned to the

No	Use case	Investment Effort	Project Effort	Weighted Effort	Benefit	Benefit-Effort Ratio
1	Initial state modeling	1,7	1,1	1,5	2,5	1,67
2	Design option analysis	1,7	0,9	1,5	2,3	1,53
3	Visualization	1,0	0,7	0,9	2,5	2,73
4	Structural analysis and dimensioning	2,5	1,4	2,2	1,9	0,86
5	Coordination	1,5	0,8	1,3	2,6	1,99
6	Design progress control	1,8	0,7	1,5	2,0	1,35
7	Drawing generation: Preliminary design	1,8	0,8	1,5	2,3	1,53
8	Safety design	1,8	1,3	1,7	1,7	1,01
9	Design approval	2,0	0,8	1,7	2,1	1,26
10	Cost estimation	1,9	0,6	1,5	2,5	1,71
11	Bill of quantities	2,1	0,9	1,8	2,6	1,47
12	4D Execution planning	1,8	0,9	1,5	2,3	1,56
13	Logistics planning	2,0	1,3	1,8	1,8	1,01
14	Drawing generation: Detailed design	1,8	1,0	1,6	2,2	1,39
15	Construction progress monitoring	1,9	0,8	1,6	2,1	1,34
16	Change management	1,8	0,9	1,5	2,3	1,46
17	Billing	2,2	1,0	1,8	2,2	1,23
18	Issue management	1,6	0,9	1,4	2,4	1,73
19	As-built documentation	2,3	1,5	2,0	2,6	1,31
20	Operation and maintenance	2,4	1,3	2,1	2,7	1,30

Fig. 3. Aggregated results of effort-benefit assessment of the individual use cases conduct by 40 German BIM experts

"Raise" scenario, and the use cases with benefit-effort ratio between 1.0 and 1.2 were assigned to the "High performance" scenario. It must be noted that the higher scenario includes all use cases of the lower one. The use case "Calculation and dimensioning" has not been included due to its very low effort-benefit ratio of 0.86.

Figure 4 depicts each of the 20 use case in an effort-benefit diagram. In addition, it maps colored areas representing the individual scenarios "Entry", "Raise" and "High performance". The boundaries of the areas are determined by the effort-benefit ratio thresholds as defined above.

Based on a careful tradeoff analysis and taking into account the synergies between the use cases, BIM4INFRA2020 recommended to make the "Raise" scenario mandatory for public construction projects. At time of writing, the government has not yet taken a decision in this regard, but is expected to do so very soon.

For more details, the reader is referred to the final report on the definition of the scenario that has been published on the BIM4INFRA2020 website (BIM4INFRA 2018b).

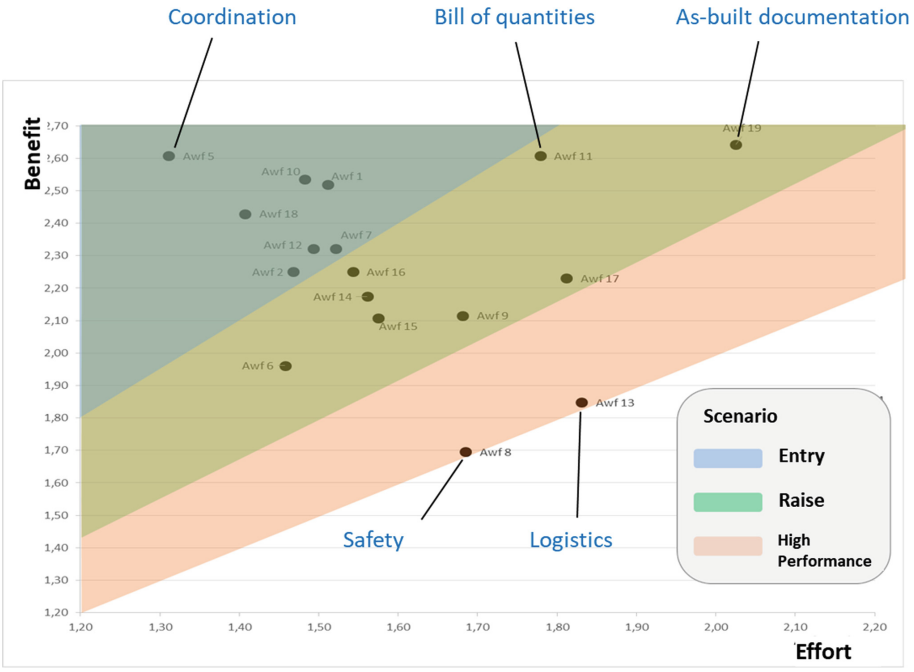

Fig. 4. Localization of the individual use cases in the effort-benefit diagram. The colored areas visualize the individual scenarios "Entry", "Raise" and "High performance".

5 Guidance and Supervision of BIM Pilot Projects

In the frame of the BIM4INFRA2020 project, seven BIM pilot projects have been conducted and intensively supervised in order to identify potential shortcomings and technological gaps that must be addressed before installing the mandatory use of BIM for all infrastructure projects. These six pilot projects were conducted:

- 3 bridges
  - Highway A99, Bridge 27/1
  - Highway A1, Bridge 533
  - Federal Road B31, Gauchachtalbrücke
- 1 tunnel
  - Highway A44: Eastern Tunnel Chain
- 1 resting place
  - Highway A7: resting place
- 1 watergate
  - Watergate Wedtlenstedt

Figure 5 depicts the BIM models of four of these six BIM pilot project.

In all projects, the focus was on the interaction between the public clients and the contracted partner. Specifically, BIM4INFRA2020 advised the projects in defining

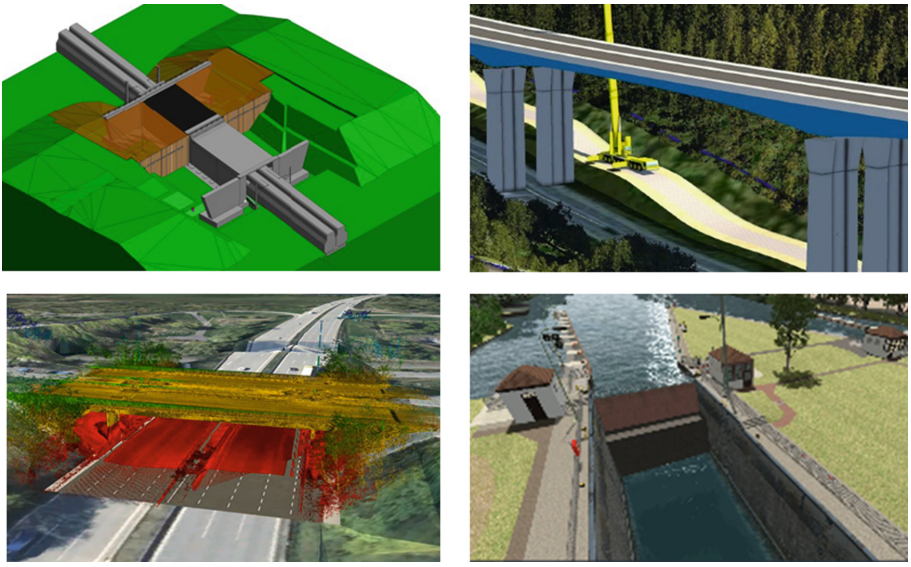

Fig. 5. Visualization of the BIM models of four of the six pilot projects supervised and supported by BIM4INFRA2020

appropriate Employer's Information Requirements (EIR), helped in analyzing the BIM Execution Plans and provided support in checking the received models for completeness and consistency. In order to investigate different aspects and learn about potential pitfalls, the construction projects applied the BIM methodology in different setups and in different phases of the building lifecycle. The lessons learned were documented in detail and published in respective project reports.

The most comprehensive project in terms of cross-phase coverage was the A99 BW27/1 project where the early design, the detailed design and the construction phase were covered (Fig. 6, Fig. 7). In all phases, BIM models were created and handed over to the client. Particularly challenging was the fact that all three phases were conducted by different companies using different BIM authoring tools, which required the extensive use of the vendor-neutral format Industry Foundation Classes (IFC) to hand over the models between the different design phases. The respective lessons learned on the proper configuration of import and export modules were published in a comprehensive technical report (Trzeciak and Borrmann 2018).

While the pilot projects were conducted without major problems, the required effort was extraordinarily high due to insufficient knowledge and experience on both, the client and suppliers side. Accordingly, it became clear that precise guidelines were required to enable the market at large to conduct BIM projects on a broad basis with reasonable effort. At the same, the awareness was risen that the industry's shift to BIM-based working practices required a transition phase with necessary investments (organizational and financial) on all sides, before the payoff in terms of more efficient project execution can be delivered.

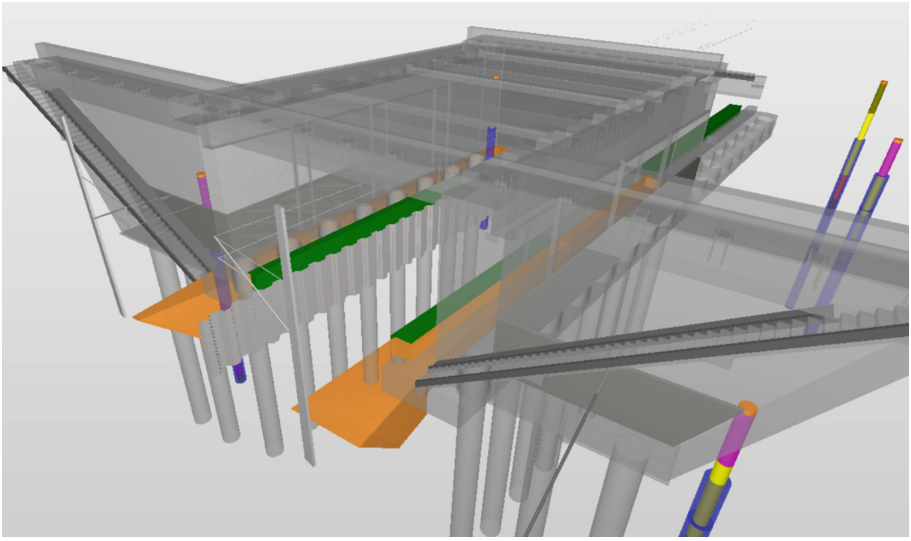

Fig. 6. Detailed model of the BIM pilot project Highway A99 Bridge 27-1

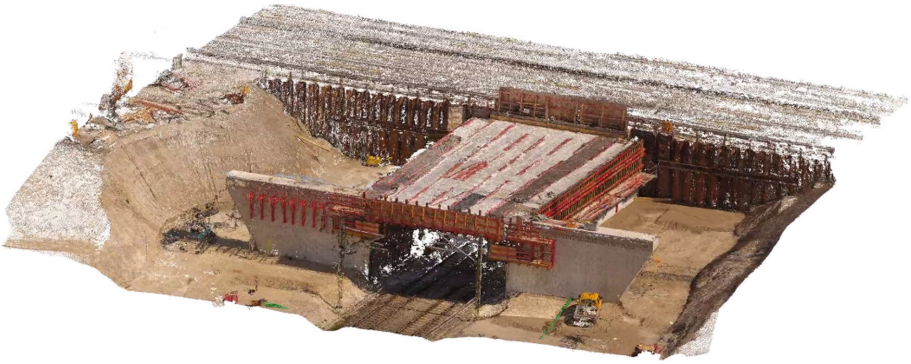

Fig. 7. Photogrammetrically created point cloud of the final bridge after construction

6 BIM Guidelines

In order to document the knowledge gathered in various pilot projects (including those mentioned in Sect. 5) and make it available to the public, BIM4INFRA2020 created 10 comprehensive guideline documents addressing the fundamental aspects of BIM project execution. In detail, the guideline documents address:

1. Basics and overall process
2. Employers Information Requirements (including templates and examples)
3. BIM Execution Plan (including templates and examples)
4. Specification of BIM services (related to contract and honorarium)

5. Contract templates
6. BIM use cases
7. BIM discipline models and Levels of Development
8. Vendor-neutral data exchange
9. Data exchange using IFC
10. BIM Technology

The guidelines add up to 250 pages in total and are available online free of charge (BIM4INFRA 2019). The target audience is AECO professionals on both client as well as supplier/contractor side.

An example from Guideline 6 is provided in Fig. 8.

Fig. 8. Detailed description of the BIM use cases specified by BIM4INFRA2020 in Guideline 6

7 Database Concept

As a result of the development of BIM4INFRA2020, it was identified that, in addition to the preparation of guidelines, a technical support of the public clients and contractors for BIM-based project management is necessary.

For public clients, it is essential that the ordering, checking and acceptance of the relevant building information can be done in a standardized, uncomplicated and well-organized way. The public clients should be able to define and check the information requirements with the help of suitable tools. This provides the contractors with clear and consistent guidelines to enable them to implement the contracted information deliveries in a proper manner. This can improve the overall efficiency of the public

sector and the productivity of the construction industry. Clients need digital support in the definition of project-specific information requirements. This also offers an advantage for the contractors, as the internal processes for creating bids and digital models can be easily adapted to the standardized specifications.

Contractors should be supported in the creation of building models based on the defined Employers Information Requirements (AIA) by appropriate software systems. Currently, the contractors must adapt the objects of the building models to the specified AIA in each case according to the specific project. If AIA-compliant templates were available for certain model objects, the model creation could be simplified and made more efficient. There are also advantages for the client, since the delivered models have a standardized structure and contain fewer errors.

The handover of results during and at the end of project phases is carried out in digital model-based form. For this purpose, appropriate systems for submission and checking by the public client must be provided. Public clients need tools for checking digital models in order to be able to compare the AIA with the data delivered by the contractors. Automated checking reduces errors and ensures high model quality. Test rules should be provided in a standardized form. This allows the contractor to carry out a preliminary check of his digital models to be delivered in order to avoid rework at an early stage.

The following recommendations for actions are based on the analysis of the international and national status quo. The corresponding report is available at (BIM4INFRA 2017). The functionalities of the individual databases or modules are listed in the following. Access to the data and individual functions should be made possible using web interfaces and web portals.

Classification and Property Database

In order to enable a seamless exchange and consistent reuse of digital building models, the objects must be described and classified in a standardized way. Classification systems and property databases are used for this purpose. Therefore, it is recommended to implement databases and corresponding user interfaces for the creation, management and use of classification systems and object properties. High quality, adapted to national regulations, and high availability must be ensured. In addition, an international coordination and linking should be promoted. The definition of the content must be carried out in close coordination with all stakeholders. Classifications and properties are maintained by individual expert groups. To ensure a consistent structure and to avoid duplication or ambiguity, overall coordination and quality management is necessary.

Employers Information Requirements Module

Classifications and properties form the basis for the definition of the AIA. Configurable templates should be made available to the public clients to create the precise information requirements for different phases and use cases. The AIA database maps the information requirements for the digital building models, i.e. information requirements can be defined for individual BIM use cases for the building models and objects to be included. Extensible templates for standard tendering procedures can be published in the AIA database, depending on the public client, the type of building and the size of the project. The database is also used to store project-specific AIA that can be re-used

in similar projects. As a rule, project-specific AIA should be created based on AIA templates; however, they can also be customized or enhanced. The AIA are provided in machine-readable form. Thus, the requirements for the model objects can be transferred to existing tools. In addition, machine-readable checking rules are also generated, so that a quick check of the submitted models with regard to the AIA is possible.

Object Template Database

Configurable BIM object templates should be used for model creation. The object templates should satisfy the AIA so that subsequent modifications of a model object are not necessary. To enable contractors to ensure that they use suitable BIM object templates, a certification database with an associated quality assurance concept should be implemented. The configuration of BIM object templates using project-specific AIA should be as automatic as possible. The AIA for model objects should be provided in an evaluable and uniform format. With the help of software tools that can also be used by BIM object template providers and integrated into their own products, it should be possible to adopt, test and configure a BIM object template.

The interaction of the individual databases and modules is shown in Fig. 9. The described functionality is currently under development by the German Centre for the Digitisation of the Construction Industry (BIM Germany).

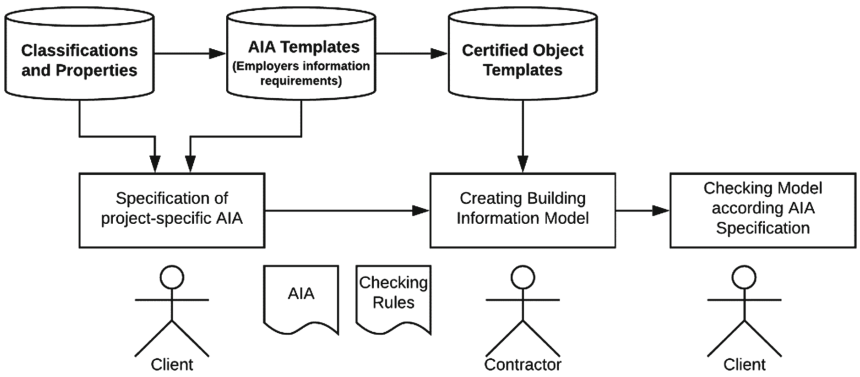

Fig. 9. Databases and modules of the future BIM portal for Germany

8 Conclusion

The BIM4INFRA2020 project provided an important corner stone for the broad implementation of BIM in Germany. By supervision of the BIM pilot projects and the intense consultation with various stakeholder groups, the most critical hurdles were identified. It became apparent that the BIM implementation process is at risk to be slowed down by the limited experience and capabilities of both, the public administration as well as the supplier side. The starting date for the mandatory use of BIM in federal infrastructure projects has been accordingly shifted to December 2020. The exact scope of the BIM mandate has not been specified but the groundwork conducted by BIM4INFRA2020 provides a solid basis for decision making.

The most important results of the BIM4INFRA2020 project were (1) the definition of the BIM 2020 scenarios by assessing the BIM use cases, (2) the publication of comprehensive BIM guidelines, and (3) the database concept. All these results provide crucial building blocks for implementing the German BIM roadmap.

Recently, the German Centre for the Digitisation of the Construction Industry (BIM Germany) was launched by the German government (BMVI 2020). It covers both the infrastructure as well as the housebuilding sector and will continue the work of BIM4INFRA2020 by pushing forward standardization and harmonization, developing a comprehensive training concept, providing consultancy and support for BIM projects and creating a vision for the future digitalization of the German construction sector.

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