CAD INTEGRATION FOR THE PETRA IV PROJECT

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Abstract

The PETRA IV project at DESY in Hamburg aims for a new, 4th generation light source with first light in 2032. It comprises the installation of a completely new, 2.3 km long 6 GeV electron storage ring and a new injection chain, installation and refurbishment of 31 photon beam lines with 60 end stations, and the construction and refurbishment of 49 buildings including a new 600 m long underground experimental hall.

The project will reuse existing tunnels and halls of the PETRA III light source, and targets a dark time without beam of only 30 months, which is a challenging task that requires thorough planning. To meet this challenge, a comprehensive CAD model has been set up that integrates the data of all participants: construction, photon science, accelerator, campus and logistics.

The model comprises representations of all systems and subsystems in different abstraction levels. A strict structure aligned with the project's WBS and PBS, extensive use of interfaces, and a focus on review and change management processes ensure that the model is complete, consistent and correct and will remain so throughout the entire life cycle of the project.

INTRODUCTION

Large scale accelerator projects pose exceptional challenges on design coordination and the design process. PETRA IV is representative of these challenges in several respects: the project comprises a new, 2.3 km long accelerator with more than 4000 components, 49 buildings including a 600 m long underground experimental hall, and 31 photon beamlines. The disposal of the existing PETRA III accelerator, demolition of three existing experimental halls, construction of the new hall and installation of the new accelerator need to fit into a 30 month dark time, conducted by teams drawn from multiple DESY departments and groups, and external contractors.

The diversity of stakeholder needs constitutes a first challenge to the integrated design model. Project leadership requires a reliable overview of project structure, design status, and consistency across work packages. Accelerator physicists, beamline scientists, civil engineers and infrastructure specialists ask fundamentally different questions, and the integrated model must serve all of them to be useful to the project.

Responsibilities and ownership pose the challenge that the work packages conducting the design work need to be responsible and accountable for their work, without altering or the need to duplicate work outside their remit, to ensure consistency across the project.

This leads to the third, and in practice often most critical, challenge of interfaces. Large projects rarely fail within the domain of single responsible group, but more likely at the boundaries between groups. Requirements and design decisions need to be communicated clearly and reliably, avoiding unnecessary repetition or delay of design work due to incomplete or changing interfaces, and preventing that items fall between the cracks due to unclear responsibilities and scope definition.

Finally, the model must remain useful across all project phases – from conceptual layout through detailed engineering, tendering, installation, and into operation and maintenance. The type of information required, and the precision with which it must be represented, changes substantially across these phases. A model architecture that is not designed for this evolution will either be abandoned as requirements change or will require costly reconstruction.

METHODS

The integrated design model of PETRA IV has been planned from the outset to address the organisational and technical challenges described above. Several principles guide its architecture.

Comprehensive Design Model

A comprehensive Computer Aided Deign (CAD) integration has been established at DESY as part of the PETRA IV project. This model includes all project relevant buildings and tunnel systems as well as the entire machine equipment along the storage ring and its pre-accelerator complex, represented in different configurations (current state and target design). In addition, the model incorporates user systems, experimental installations and technical infrastructure, including supply routes, escape paths and transport routes. It serves as a single source of truth and provides all stakeholders involved in construction and design processes with a complete and reliable geometric context.

Structure

The model hierarchy – complex, facility, area, unit, component – is explicitly aligned with the project's Product Breakdown Structure, as managed in the PLM system. It has been adapted from the physical hierarchy of the ISA-106 standard [1]. This alignment is not merely organisational convenience: it ensures that each work package owns and is accountable for a well-defined portion of the model, and that design review processes can be conducted within the boundaries of individual work packages or work package groups. The linkage to the PBS also provides the foundation

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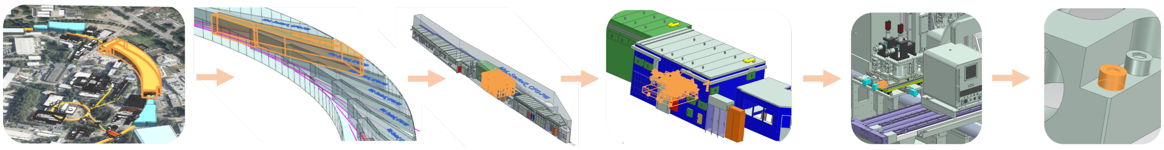

Figure 1: CAD structure allows vertical navigation from the entire program to every individual part.

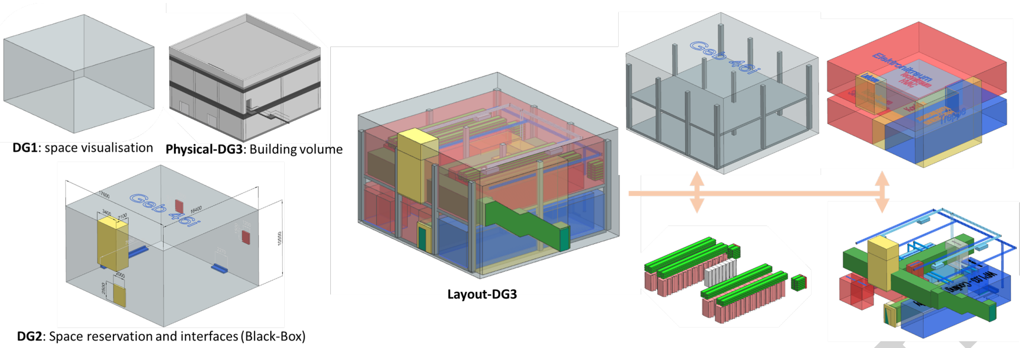

Figure 2: Level of detail in case of a building design. The building is represented in different abstraction levels. The layout-DG3 model separates functionally into a construction layout, while a physical-DG3 shows the engineering design.

for tracing design elements back to requirements, supporting formal verification and validation processes as the project matures. The model structure allows seamless navigation over five orders of magnitude in size (Fig. 1).

Modularisation

In the PETRA IV integration model, the system is organised into clearly defined modules, each representing a physically bounded and functionally self-contained unit with explicit interfaces to its environment. Modularity is applied consistently across all design levels, from large-scale structures such as accelerator arc to technical subsystems like local media supplies or beamline optics. This modular approach enables structured integration and facilitates parallel development throughout the entire PETRA program.

Multiple Levels of Detail

Every module in the model is represented at three levels of geometric detail (Fig. 2). DG1 models capture only rough outer envelopes and are used for early-stage visualisation and communication with stakeholders who require an overview of the project without engineering detail. DG2 models define space reservations including all necessary operational and maintenance clearances, and — critically — specify all interfaces to adjacent systems. DG3 models provide the full engineering representation, with a complete bill of materials down to individual fasteners. This progression maps directly onto design maturity: DG1 is appropriate at conceptual stage, DG2 at the point where interfaces must be fixed for concurrent engineering to proceed, and DG3 when detailed design is finalised. The multi-level approach also ensures that the comprehensive integration model remains navigable and computationally tractable – surrounding systems can be loaded at DG1 or DG2 while detailed work proceeds on a specific subsystem at DG3.

Interfaces as Explicit Model Elements

Perhaps the most consequential design principle is the treatment of interfaces. In the DG2 representation of every module, interfaces to adjacent systems are modelled as explicit geometric elements in their own right — not implied by proximity or left to informal agreement between design teams. This applies to mechanical connections such as mounting points and bolted joints, to media connections such as power, cooling water and compressed air, and equally to non-material interfaces such as transport corridors and evacuation routes. Because interfaces are explicit, they can be defined, reviewed, and formally released at DG2 stage, before detailed internal engineering has begun. Once released, the interface definition decouples the two adjacent design teams: each can proceed with its internal design independently, with the guarantee that compliance with the frozen interface ensures overall compatibility. This principle directly addresses the failure mode — common in large projects — where responsibilities are unclear at boundaries and issues are discovered late.

Representation of Non-engineering Stakeholder Requirements

Not all stakeholders in a large project contribute geometry to the engineering design. Safety groups specify evacuation route widths and emergency egress points; logistics groups define transport clearance envelopes for the movement of large components through tunnels and buildings. Without an explicit representation in the CAD model, these requirements exist only in documents and are easily overlooked during design iterations. In the PETRA IV model, transport clearance volumes and escape route geometries are treated as modules in the same sense as any engineering component – they occupy space, they have interfaces (doors, gates, crane hook heights), and they participate in collision checks against the engineering design (Fig. 3). This ensures that

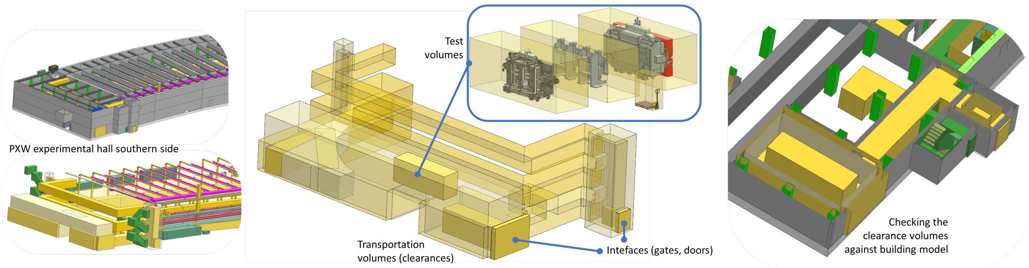

Figure 3: Transportation Planning. Left: detail of a building model and technical building equipment with transport and escape routes, centre: abstract test bodies are tested in the transport network (applicability of transportation concept).

safety and logistics constraints are enforced continuously throughout the design process, not audited retrospectively.

Anticipating Downstream Project Phases

The model is designed not only for the current design phase but with explicit consideration of the needs of later phases. Two examples illustrate this. First, the support interface of the storage ring – the set of all points where the machine must be anchored to the tunnel floor – is defined as a derived product of the DG2 interface specifications of all sub-assemblies. This allows a complete map of required fixation points to be extracted from the model and handed to civil engineering for drilling and survey preparation, independently of the state of detailed engineering design. Second, girder assemblies are represented in the model as coherent, self-contained installation units – integrating the support structure, beamline components, vacuum system, and services on a single pre-assembled carrier [2]. This representation mirrors the intended installation strategy, in which preassembled girders are brought into the tunnel and installed with minimal on-site integration work. Designing with the installation unit as the fundamental model element from the outset ensures that the engineering design remains compatible with the logistics and assembly strategy that will determine whether the 30-month dark time target can be met.

RESULTS AND DISCUSSION

The integrated CAD model is actively applied across the full scope of PETRA IV planning. Two examples illustrate its application in the current design phase.

Transport route modeling for the PXW experimental hall has demonstrated the value of representing logistics requirements as explicit geometric elements in the model. Clearance volumes for large components have been checked against the hall structure, access shafts, and building infrastructure, revealing constraints that would not have been apparent from drawings or documents alone. In the endcap buildings – the structures through which large items enter the underground hall – the modeling identified limitations in the receiving areas that restrict the handling of oversized components. A specific finding was that elevator dimensions are insufficient to transport goods on hand-operated pallet trucks, meaning that crane involvement is required for such deliveries. Identifying these constraints at the design stage allows logistics planning and, where possible, building design to be adapted accordingly, rather than discovering the limitations during installation.

A prospective application currently in preparation is the derivation of a complete fixation point map for the storage ring – the full set of anchor points where the accelerator support structures must be attached to the tunnel floor. This map can be derived directly from the DG2 interface specifications of all girder assemblies and can be extracted from the model independently of the state of detailed engineering design. It will be handed to the surveying group to guide survey preparation and drilling, allowing that work to proceed in parallel with finalisation of the detailed design.

These examples illustrate broader benefits that the integrated model provides across the project:

Single source of truth: all stakeholders — accelerator physicists, civil engineers, beamline scientists, logistics and safety groups — work from and contribute to the same geometric model, eliminating inconsistencies that arise from parallel, uncoordinated representations.

Early conflict detection: spatial conflicts between systems are identified at the design stage, when changes are inexpensive, rather than during installation, when they are not.

Concurrent engineering: DG2 interface definitions allow adjacent design teams to work in parallel once interfaces are frozen, without waiting for the internal design of neighbouring systems to be complete.

Lifecycle continuity: the model is designed to serve the project from conceptual layout through installation and into operation, with the level of detail and the information it carries evolving as the project matures.

REFERENCES

[1] International Society of Automation, "ISA-106: Procedure automation in continuous process operations". `https://www.isa.org/standards-and-publications/isa-standards/isa-106-standards`

[2] B. List *et al.*, "From lattice to engineering design: a rapid, reliable development cycle", presented at IPAC'26, Deauville, France, May 2026, paper MOP7187, this conference,